Jet Propulsion Laboratory
California Institute of Technology

# The OpenSE Cookbook: A practical, recipe based collection of patterns, procedures, and best practices for executable systems engineering for the Thirty Meter Telescope

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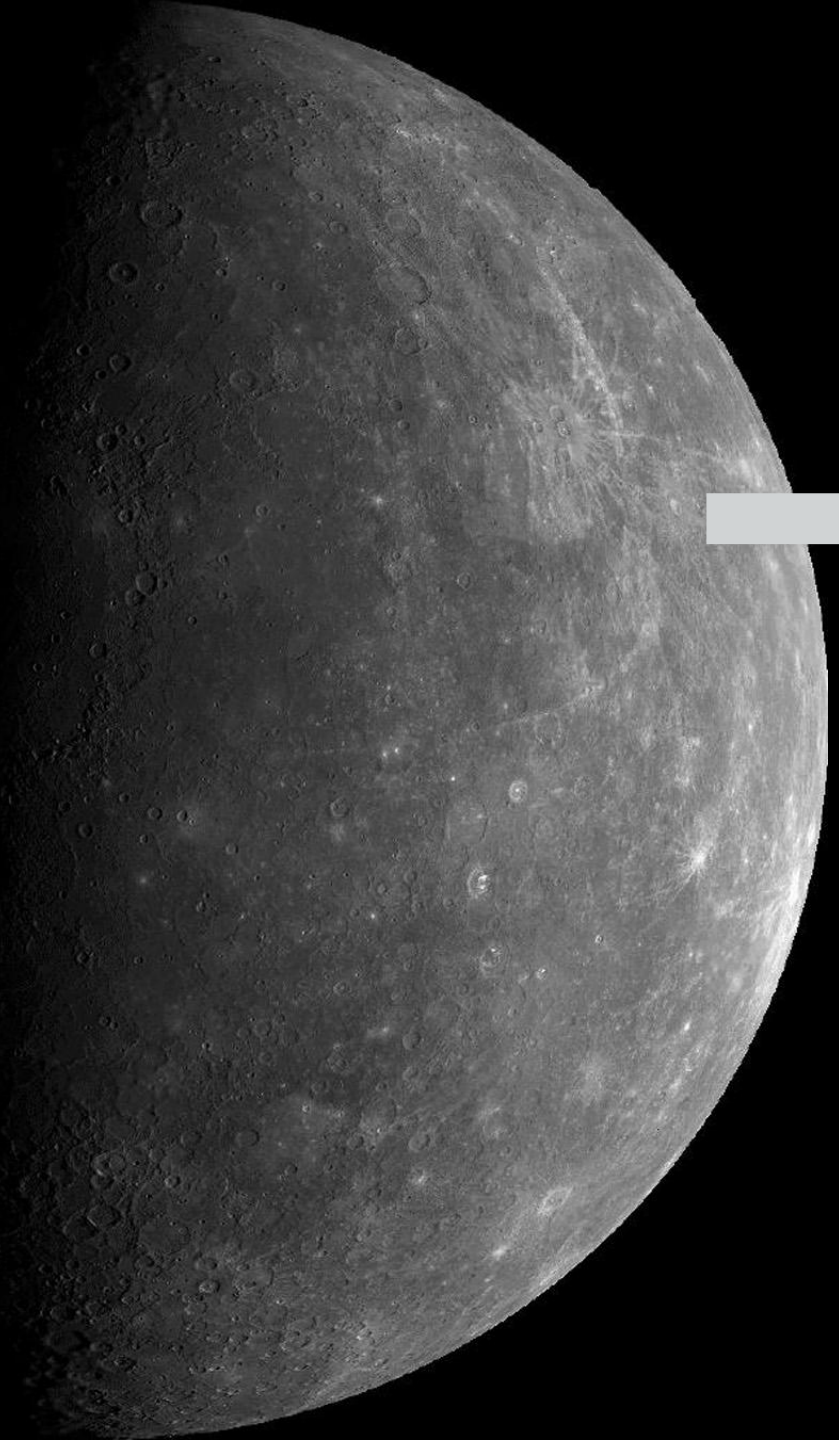
***California Institute of Technology***

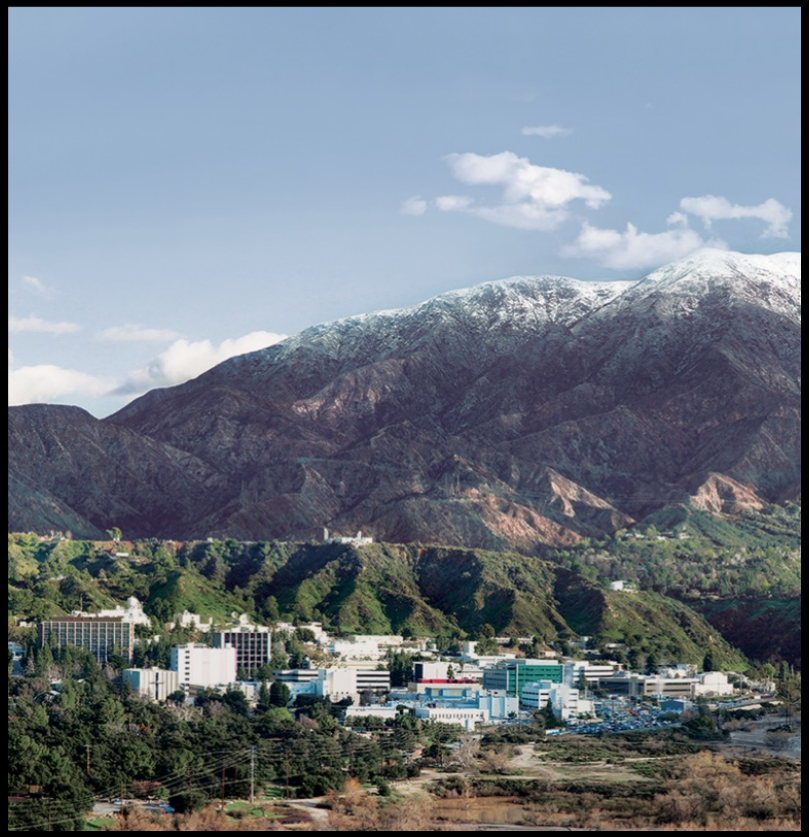
**18-22 June 2018 – OMG Technical Meeting, Boston, MA, USA**



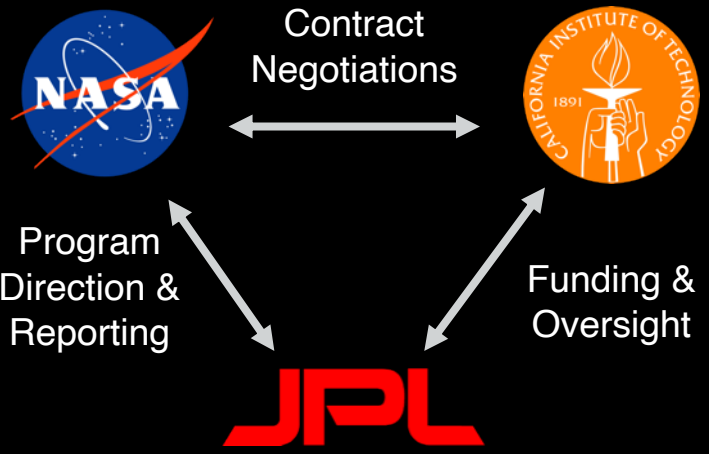
# Agenda

- Introduction
- TMT and MBSE Approach
- Cookbook Principles
- Selected Cookbook Patterns

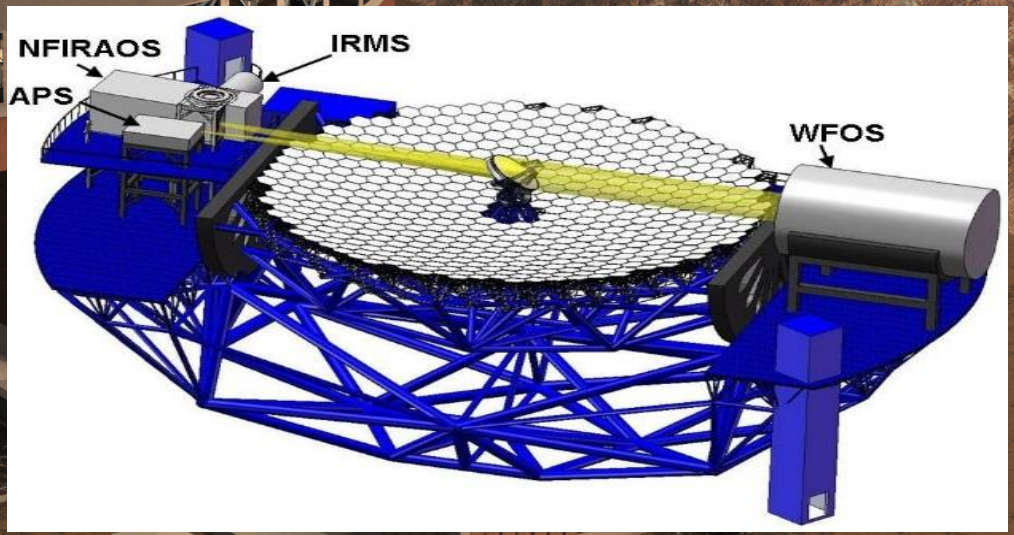
# NASA Jet Propulsion Laboratory (JPL)



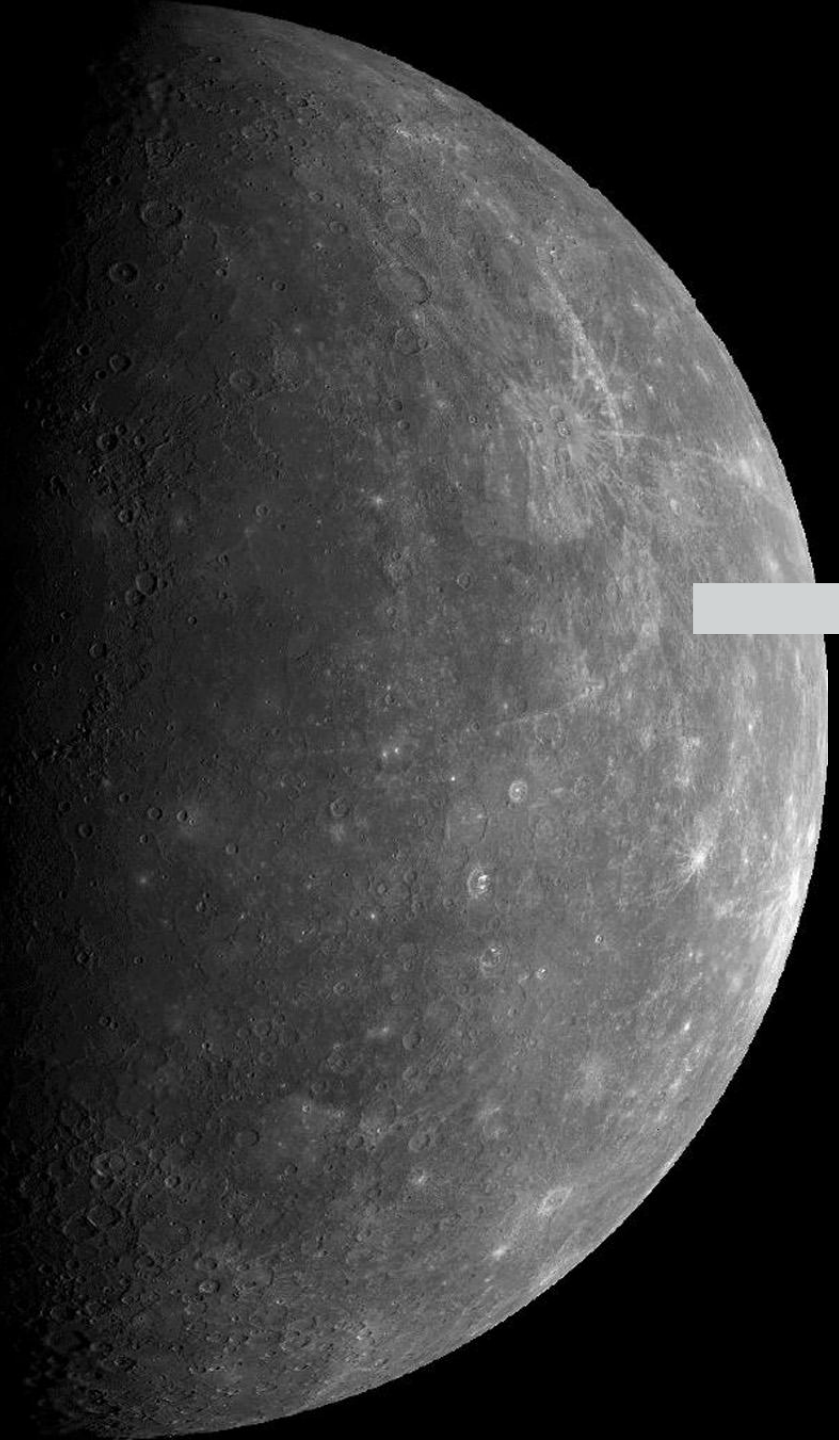
- Located in Pasadena, CA
- NASA-owned *"Federally-Funded Research and Development Center"*
- University-operated
- ~5,000 employees



# The Thirty Meter Telescope (TMT) Project




www.tmt.org



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# TMT applies “Hybrid” Systems Engineering Approach

Traditional SE

- Clear, defined deliverables
- Easily accessible
- Shallow learning curve
- Simple traceability

MBSE

- Understanding behaviors of a system
- “Rich” capability to represent complex systems

**Exploit the advantages of each approach**

# TMT MBSE Approach delivers consistent, verifiable engineering products

- Define an **executable SysML model**
- Use the model to **analyze the system design and verify requirements** on power consumption, mass, duration, pointing errors, etc.
- Produce **engineering documents**
  - Requirement Flow Down Document
  - Operational Scenario Document
  - Design Description Document
  - Interface Control Documents
- Use **standard languages and techniques, and COTS tools where practical** to avoid custom software development

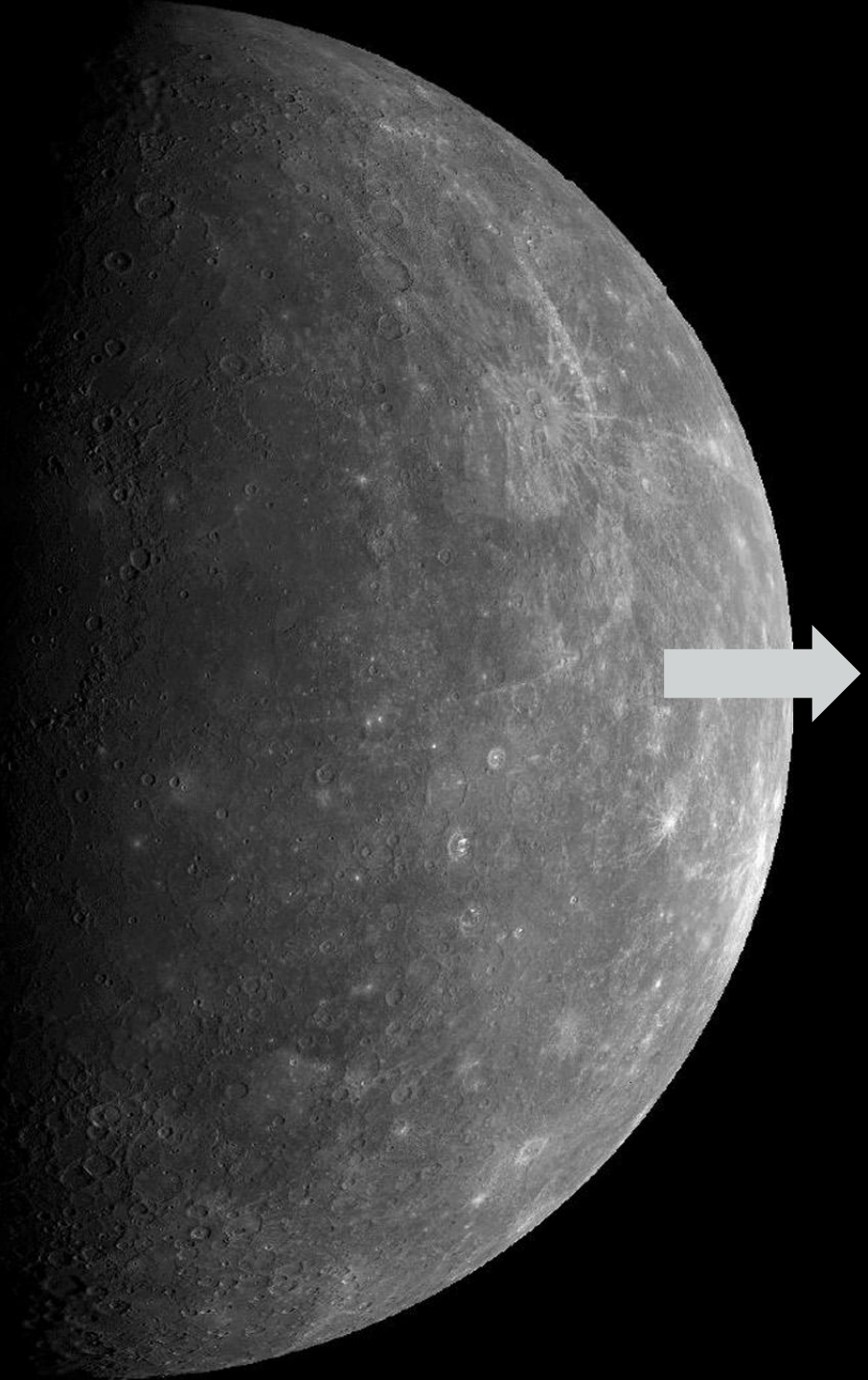
# TMT MBSE follows a well defined Modeling Approach

- Object-Oriented Systems Engineering Method (**OOSEM**), but with additional activities focusing on building an executable model
- Use case driven model development
- Challenges:
  - JPL is a **supplier** for a number of subsystems of the TMT (the **customer**)
  - Model is used by a number of teams, including TMT

**ESEM = OOSEM + Executability**

# Systems Model is developed according to ESEM using Cookbook Patterns

- Define APS Mission boundaries
- Elaborate Conceptual Architecture
- Capture Component Behavior and Characteristics
- Specify Interactions between Components
- Run Analyses



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# OpenSE Cookbook addresses Systems Engineering Concerns

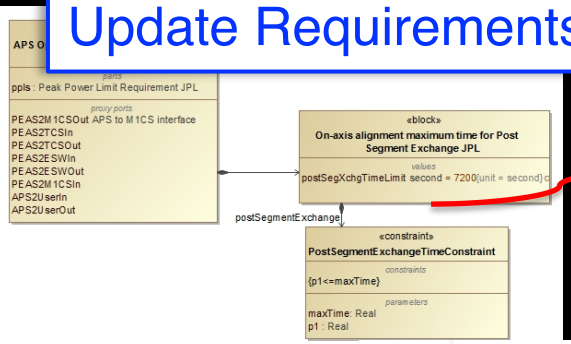
- Provides goal oriented guidance using patterns, e.g.
  - How-to Verify Requirements
  - How-to Roll-up Technical Resources
- Driven by Systems Engineering Workflows
- Enables combining patterns into more complex recipes
- Demonstrates how to build system models with available tooling - How/where do I start?
- Includes known usages in TMT production model as reference
- Commoditizes Executable Systems Engineering

# OpenSE Cookbook combines different aspects

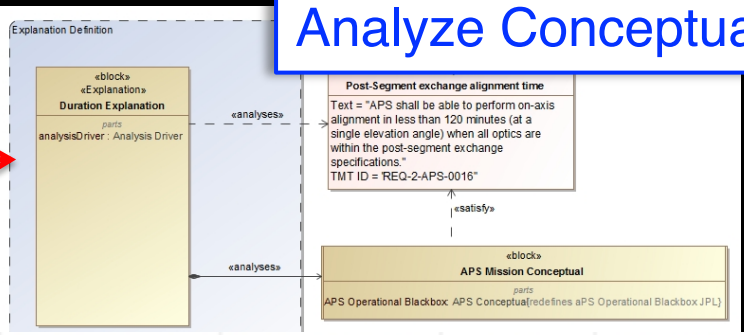
- Update 2012 “Cookbook for MBSE with SysML”
  - Focus on structure and requirements using European FP7 Active Phasing Experiment (APE) as case study
- Include Patterns developed for TMT
  - Focus on behavior and analysis workflows
- Guided by ESEM methodology
- Describe tooling support provided by JPL Systems Environment
- OpenSE model library provides commonly used elements
- Instructional examples
- Application to actual engineering team, i.e. TMT
- Template Models and recommended model organizations

# TMT Analysis workflows drive the OpenSE Cookbook

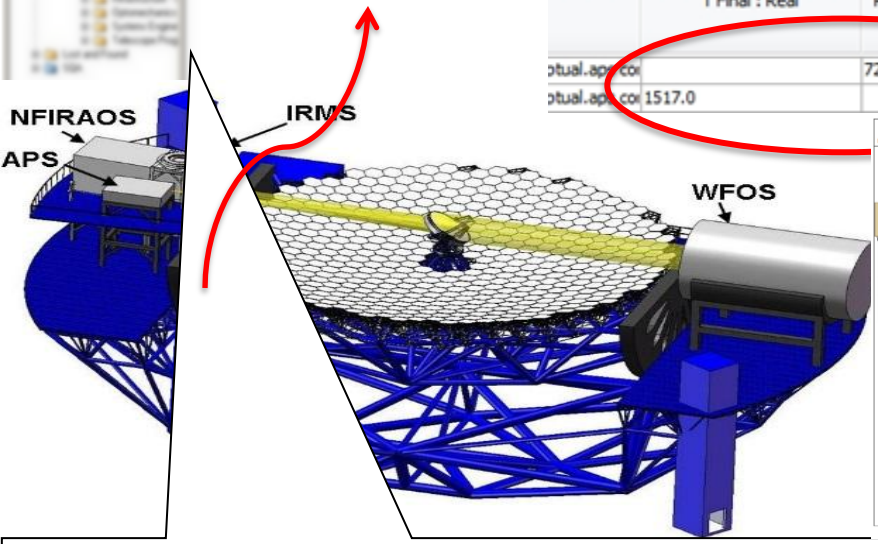
## Update Requirements 2



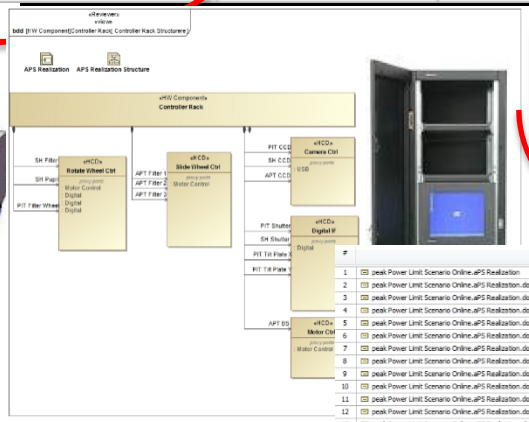

## Analyze Conceptual Design 3




| T Final : Real | Post Seg Xchg Time Limit : Second | Post Segment Exchange : Post Segment Exchange Time Constraint | Off Axis Measurement Steps : Integer | Off Axis Map Points : Integer | RB Dit : Integer | Phasing Dit : Integer |
|---|---|---|---|---|---|---|
| 1517.0 | 7200.0 | pass | 6 | 7 | 45 | 20 |




## Analyze Realization Design/Specification 4



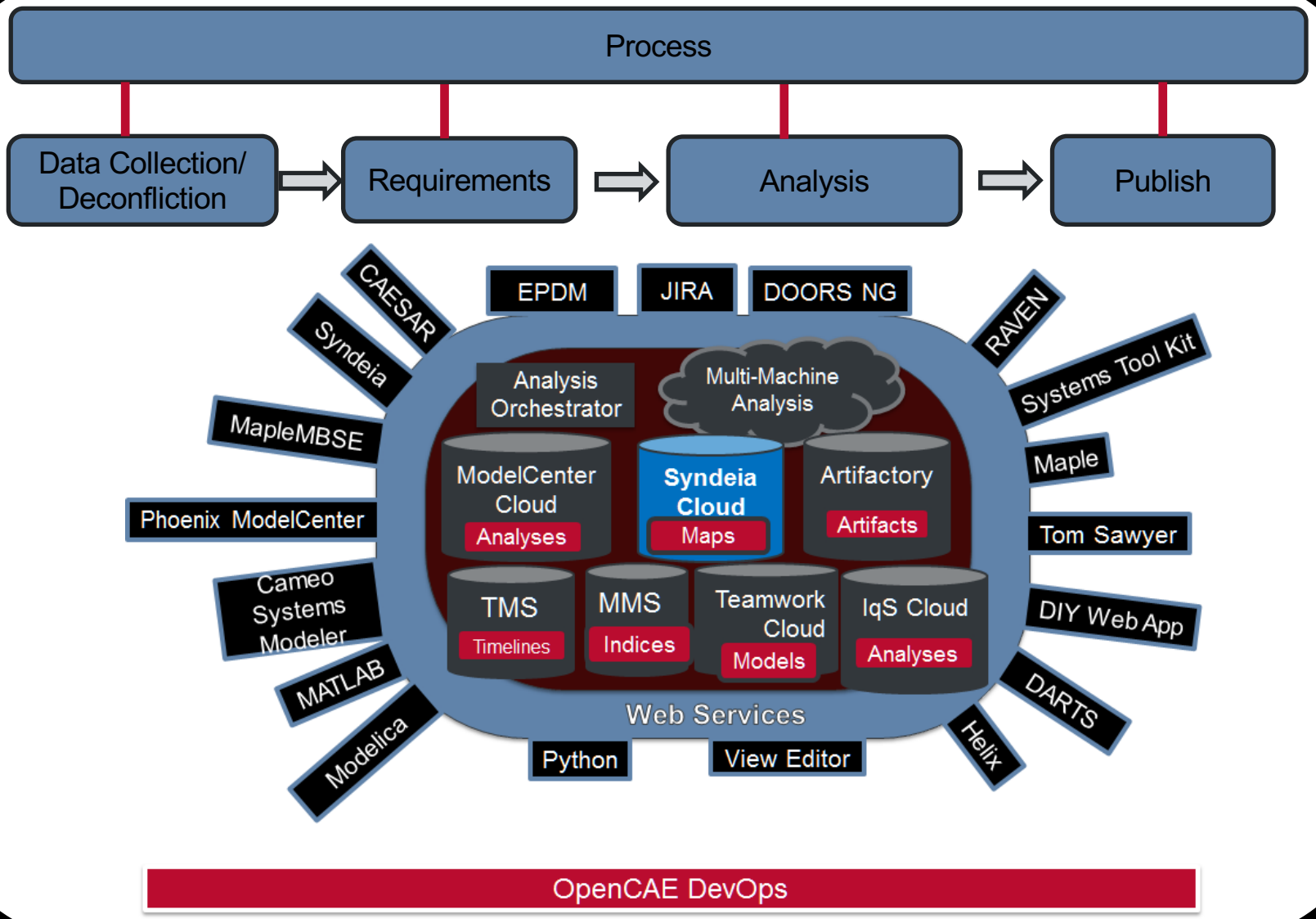
## Pass/fail

## Produce Engineering Documents 5

### Change request 1

Max duration Post-segment exchange: ~~7200s~~ 5000s
Number of exposures of 45s 4 ~~6~~
Max peak power consumption in dome: 8.5kw ~~8.1kw~~
Number of motors with 50W 10 ~~12~~

# JPL/CAE Systems Environment provides integrated Life-Cycle Support



JPL develops requirements for Systems Environment (tooling) through Case Studies

For Example:

- Requirements Management
- Interface Management
- Design Management
- Trade Studies
- Interdisciplinary Integration
- Analysis Pipeline
- Resource Management
- Timeline Management

# Using tools from OpenMBEE community

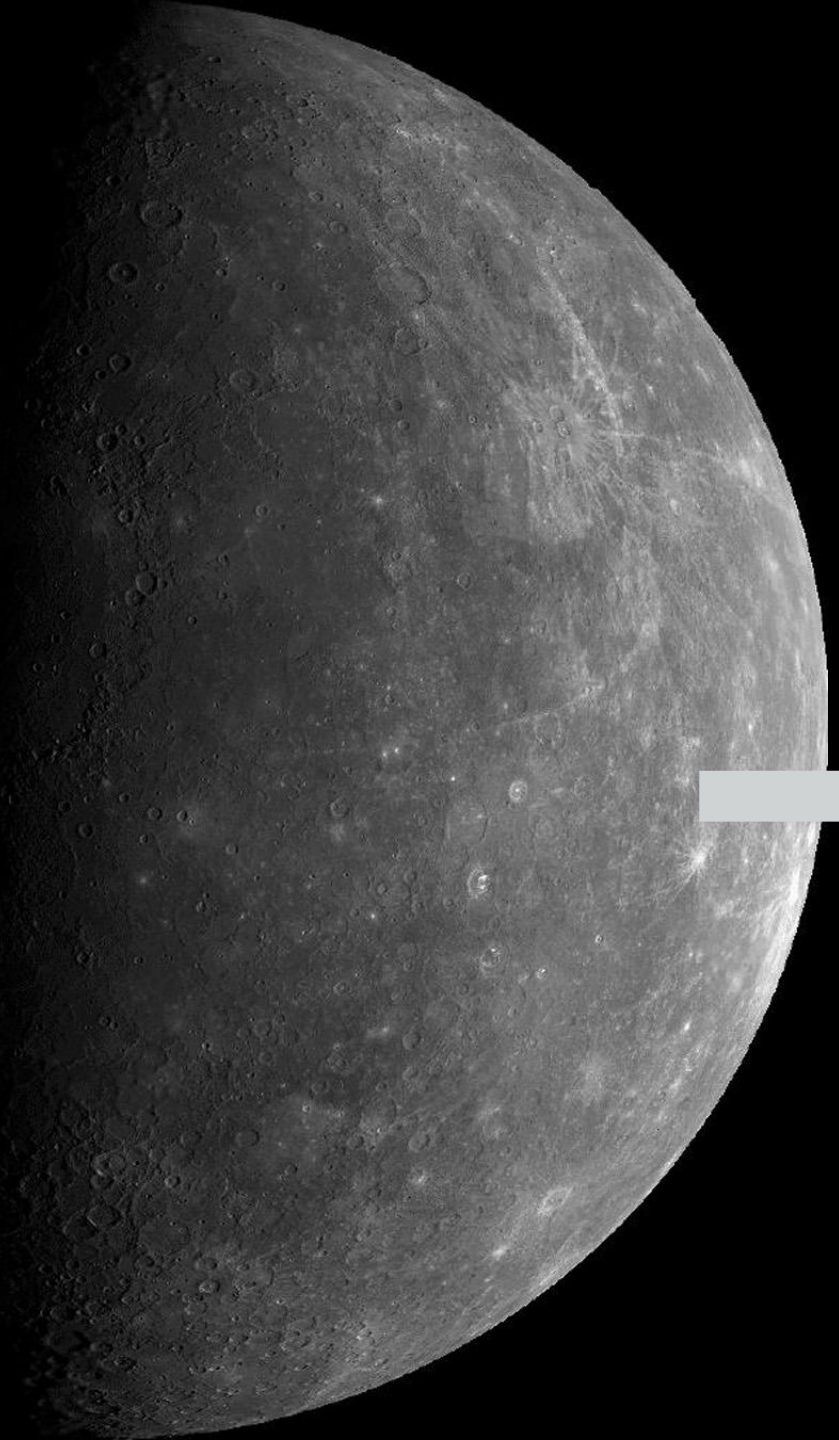
## **Open Model Based Engineering Environment**

- OpenMBEE is a community for open-source modeling software and models
  - Open source software
    - MMS, ViewEditor, MDK
  - Open source models
    - TMT, OpenSE Cookbook
- JPL is a participant and adopter of OpenMBEE software and models
- Boeing, Lockheed, OMG, NavAir, Ford, Stevens, GaTech, ESO, TMT, NASA
- Vendors participate as well
- ~200 members, annual INCOSE workshop
- www.openmbee.org

# Pattern Structure

Every pattern follows the same structure

- Intent
- Motivation
- Concept
- Consequences
- Implementation
- Known Uses
- Tooling
- Related Patterns



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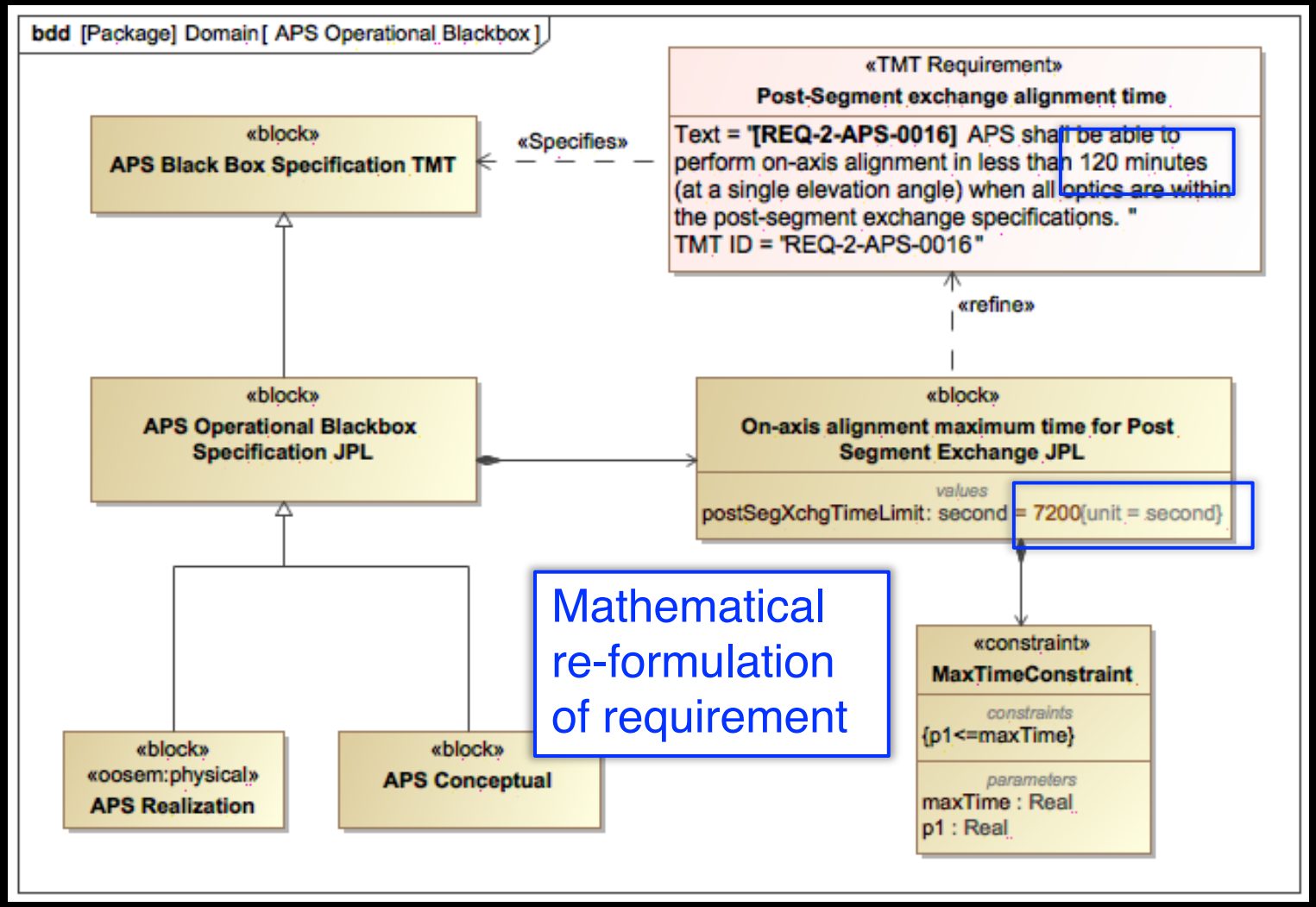
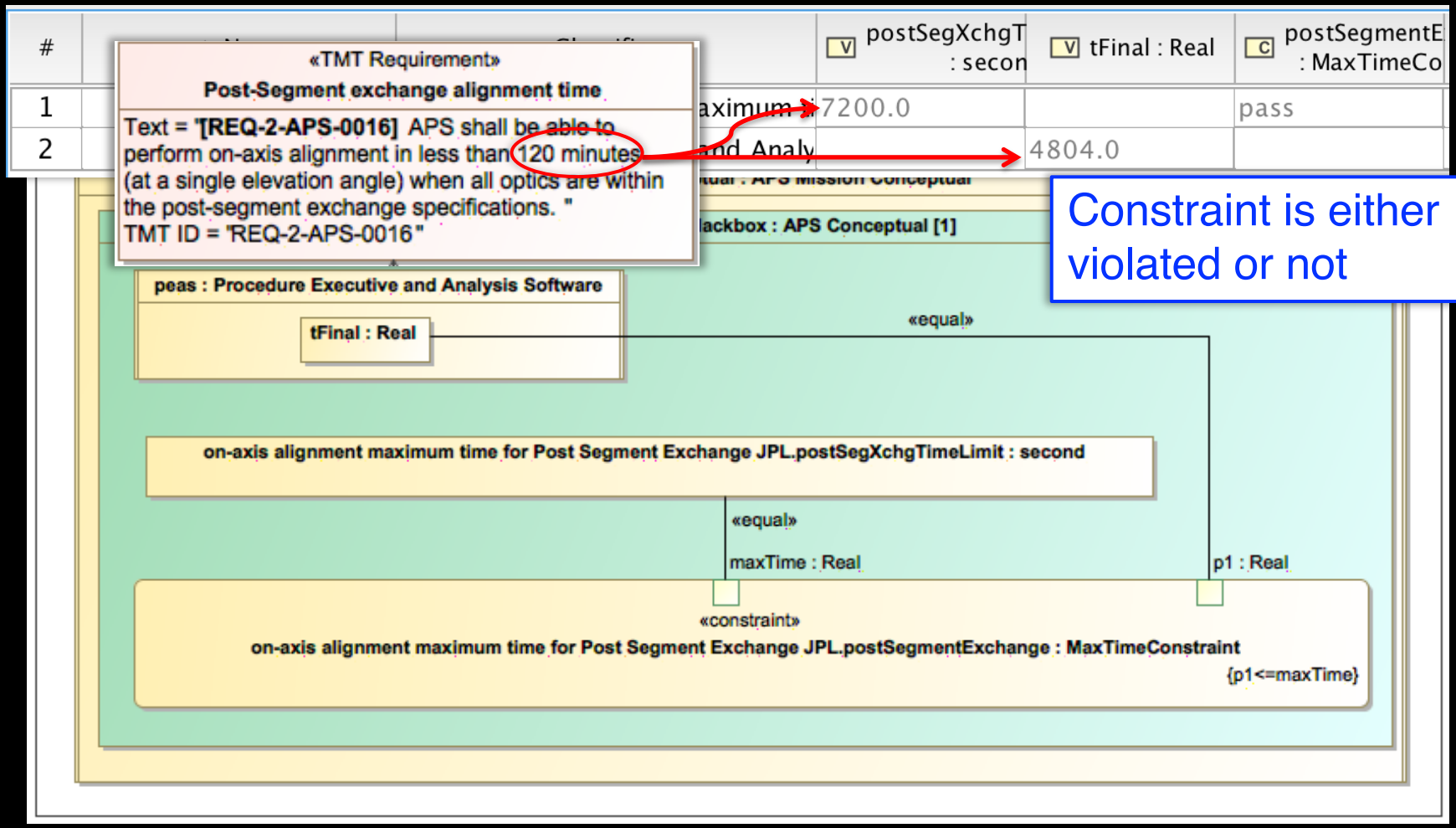
# Requirements Verification

- Intent
  - Validate requirements, verify as designed system against requirements and publish analysis results
- Cookbook Volume
  - System Requirements Management
- Educational example
  - Autonomous Ferry Transportation
- Known Uses
  - APS - Post-segment exchange timing requirements
- Tooling
  - Cameo Systems Modeler and Simulation Toolkit, View Editor
- Notes
  - Property Based Requirements links Requirements Management and System Design

# Formalizing Requirements with Property Based requirements



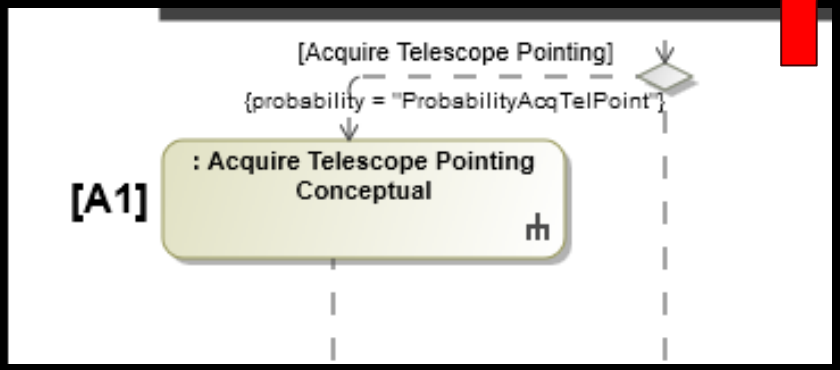
# Verifying Timing Requirements by Simulation

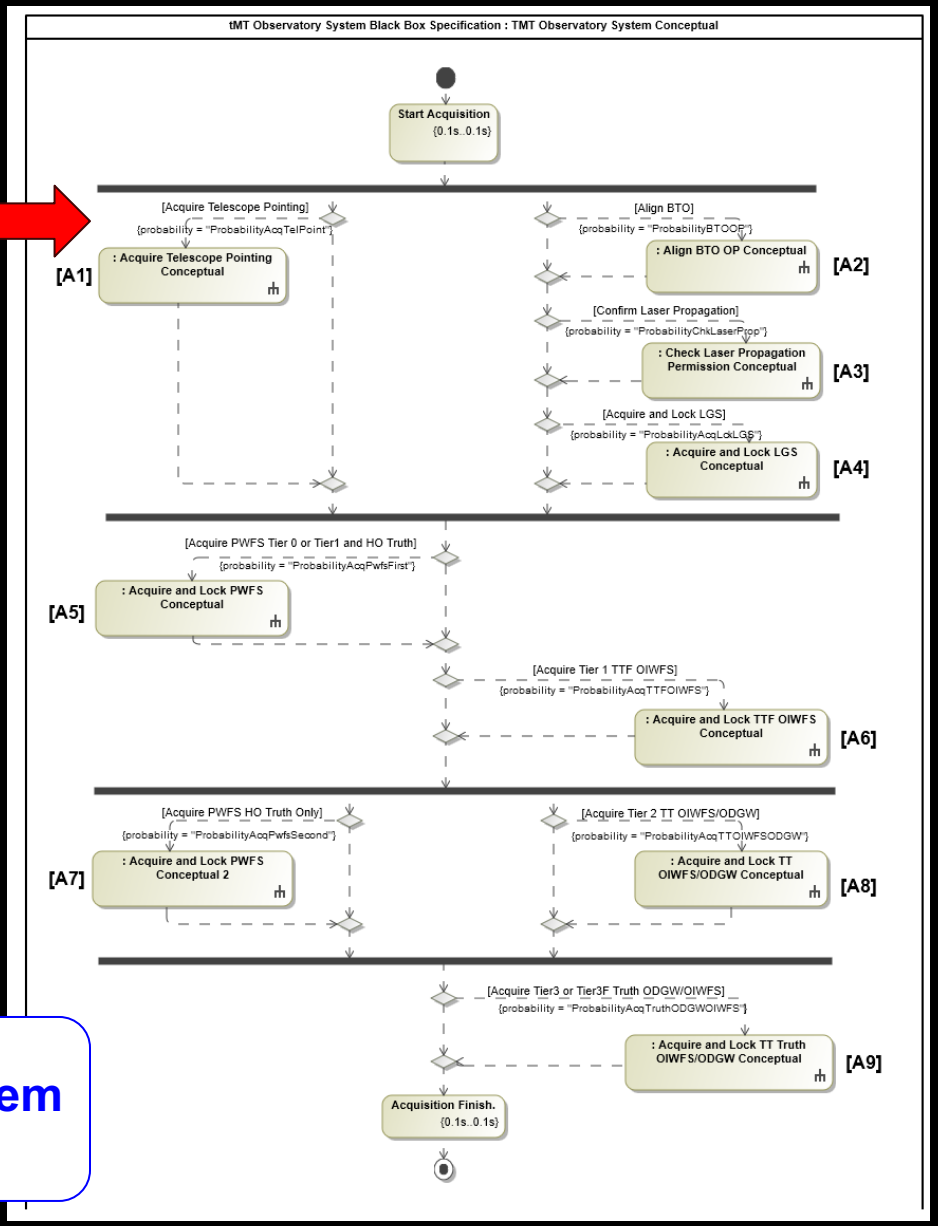


# Monte Carlo Driven Analysis

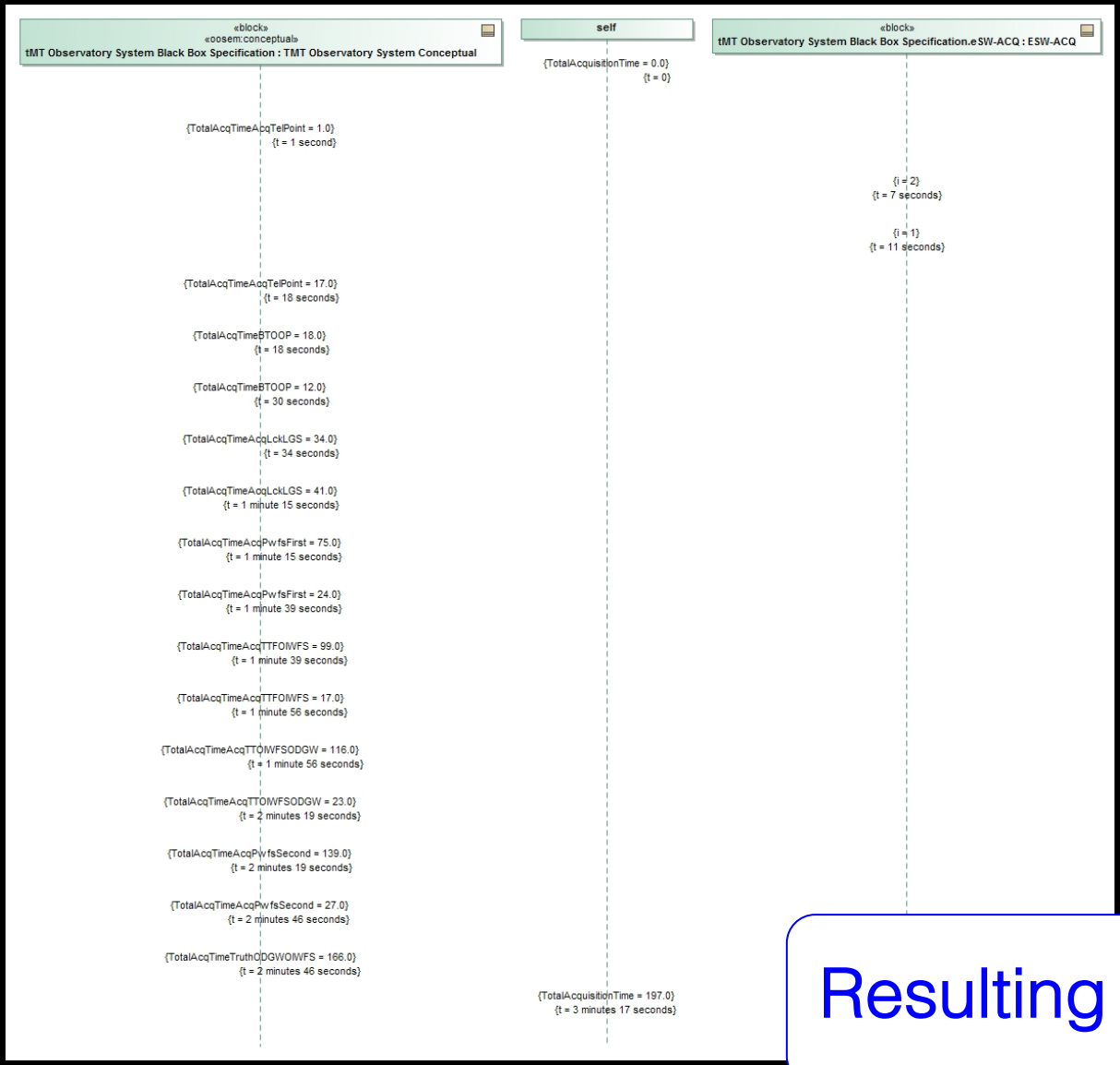
- Intent
  - Estimate the characteristics and probability of a particular behavior using modeling anchored through data.
- Cookbook Volume
  - System Analysis Management
- Educational example
  - Quadrupedal Robot
- Known Uses
  - AO - Acquire a target with IRIS and NFIRAOS
- Tooling
  - Cameo Systems Modeler and Simulation Toolkit, View Editor
- Notes
  - SysML probability concepts and distributed properties capture operational knowledge in system model

# Behavior with Probabilities




**TMT Observatory System Conceptual**

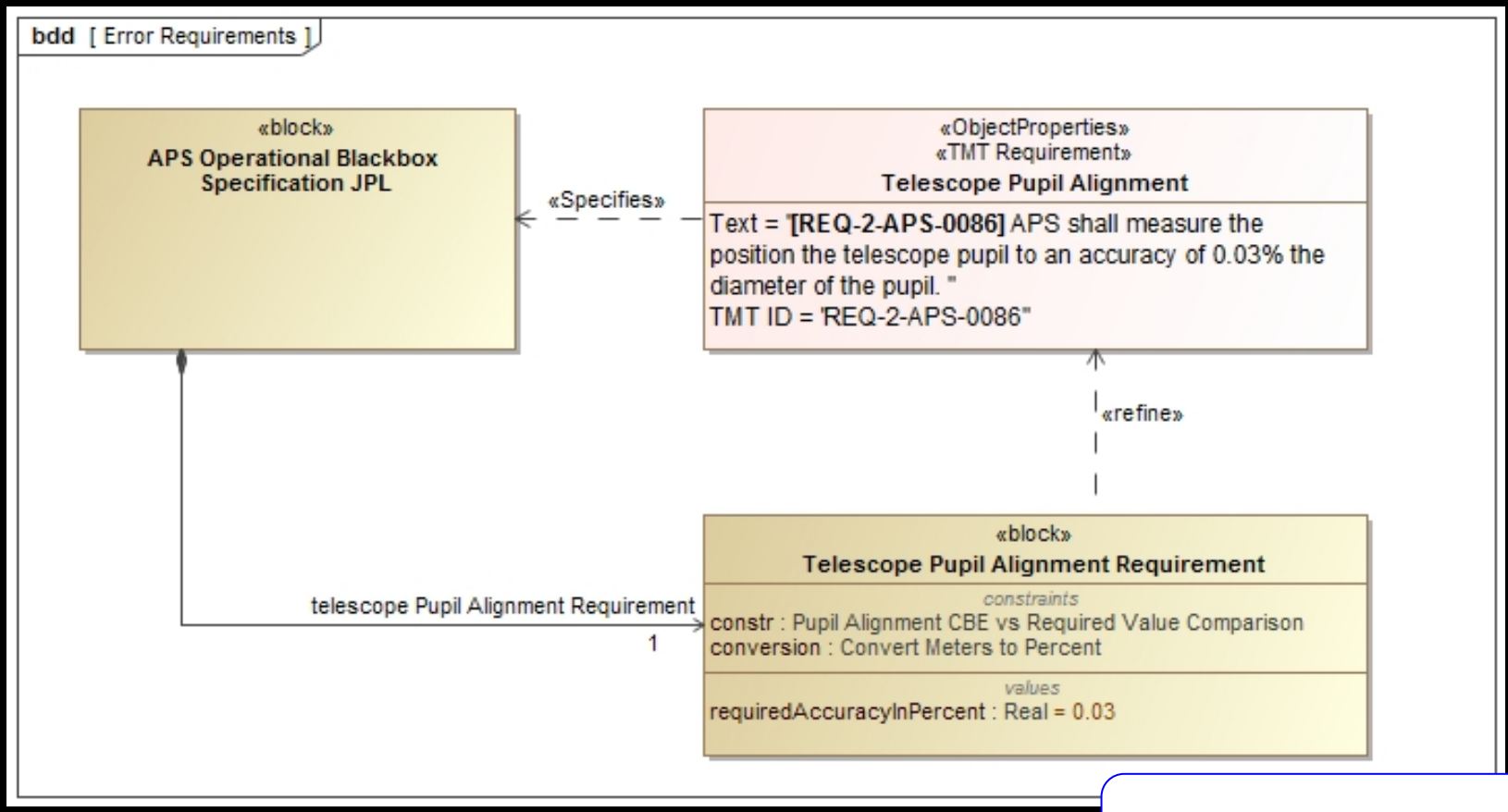



# Resulting Trace

# Error Budget Management

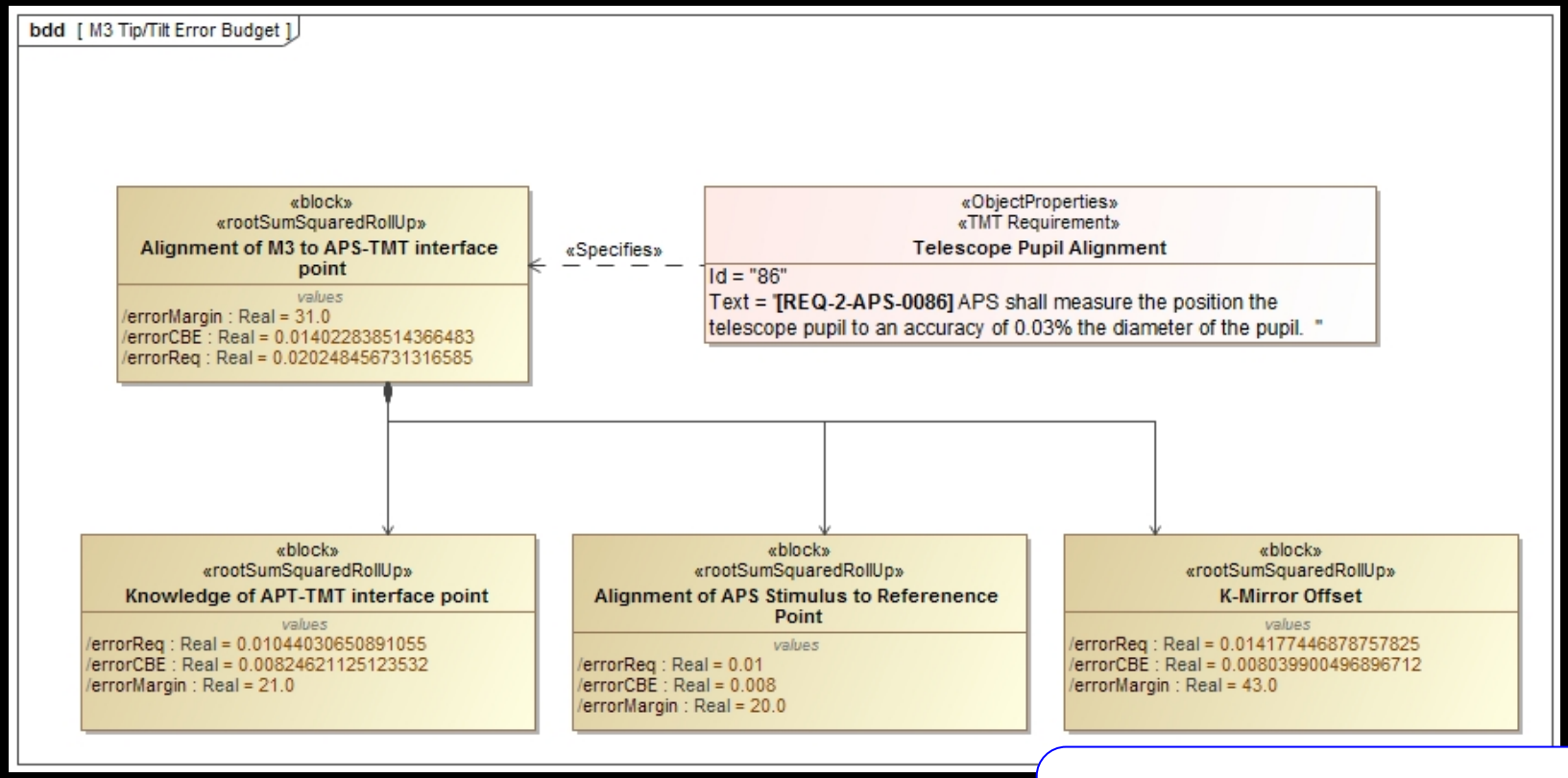
- Intent
  - Manage error budgets of technical resources such as wave front error
- Cookbook Volume
  - System Resource Management
- Educational example
  - Microscope
- Known Uses
  - APS - Alignment error of the M3 to APS interface
- Tooling
  - Cameo Systems Modeler and Simulation Toolkit, View Editor

# APS - Alignment error of the M3 to APS interface




**Context**

# Specify RSS Tree




**Application of pattern**

# Conclusions and Summary

- OpenSE Cookbook addresses SE concerns, activities, and processes
- Built on proven patterns from TMT and APE
- Supported by tooling
- Open for contributions and collaboration through INCOSE Telescope Challenge team

**Accessible at**
**https://mms.openmbee.org**

# Acknowledgements

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# References


- OpenSE Cookbook: https://mms.openmbee.org/alfresco/mmsapp/mms.html#/projects/PROJECT-ID_2_2_17_7_33_25_AM_3ccfaf88_159fe0d7ba9__7d4e_cae_tw_jpl_nasa_gov_127_0_0_1/master/document/_18_5_2_e64033a_1513276256458_934885_22190
- INCOSE SE2 Cookbook: https://mbse.gfse.de/documents/faq.html
- Karban, R., Jankevičius, N., Elaasar, M. “ESEM: Automated Systems Analysis using Executable SysML Modeling Patterns”, (to appear in the proceedings of INCOSE International Symposium (IS), Edinburgh, Scotland, 2016.)
- Karban R., Dekens F., Herzig S., Elaasar M, Jankevičius N., “Creating systems engineering products with executable models in a model-based engineering environment”, SPIE, Edinburgh, Scotland, 2016
- Karban, R., “Using Executable SysML Models to Generate Systems Engineering Products”, NoMagic World Symposium, Allen, TX, 2016
- Open Source TMT model: https://github.com/Open-MBEE/TMT-SysML-Model
- Open Source Engineering Environment: https://www.openmbee.org
- Docgen, ViewEditor, MMS: https://github.com/Open-MBEE/open-mbee.github.io/wiki/OpenMBEE-documentation
- JPL Model-Based Systems Engineering Case Study: http://omgwiki.org/MBSE/lib/exe/fetch.php?media=mbse:incose_mbse_iw_2017:iw_2017_open_mbee.pdf
- A Practical Guide to SysML, 3rd Edition, Chapter 17 by Friedenthal, Moore, and Steiner
- https://www.jpl.nasa.gov/spaceimages/
- INCOSE Telescope Challenge Team, http://omgwiki.org/MBSE/doku.php?id=mbse:telescope

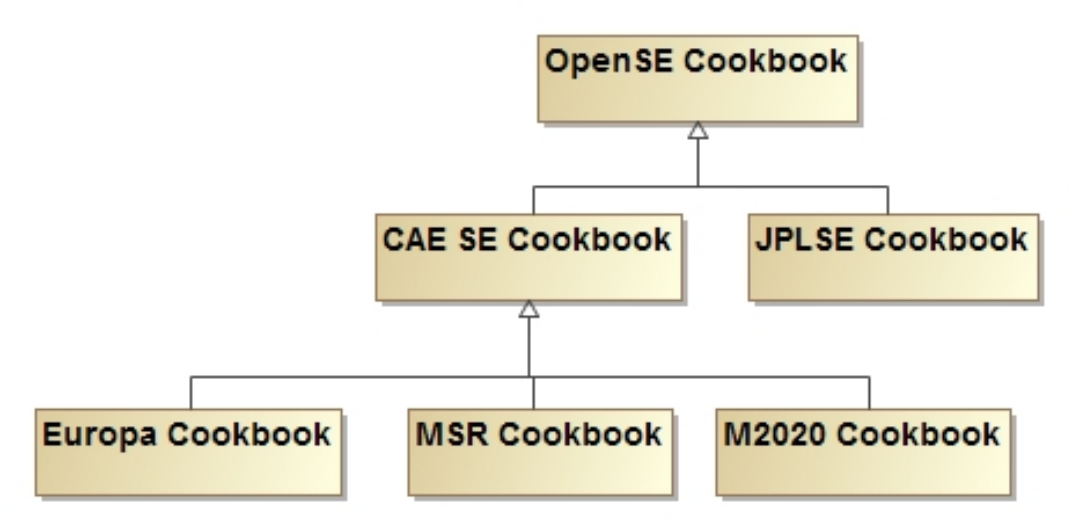

BACKUP SLIDES

# Who is Robert?

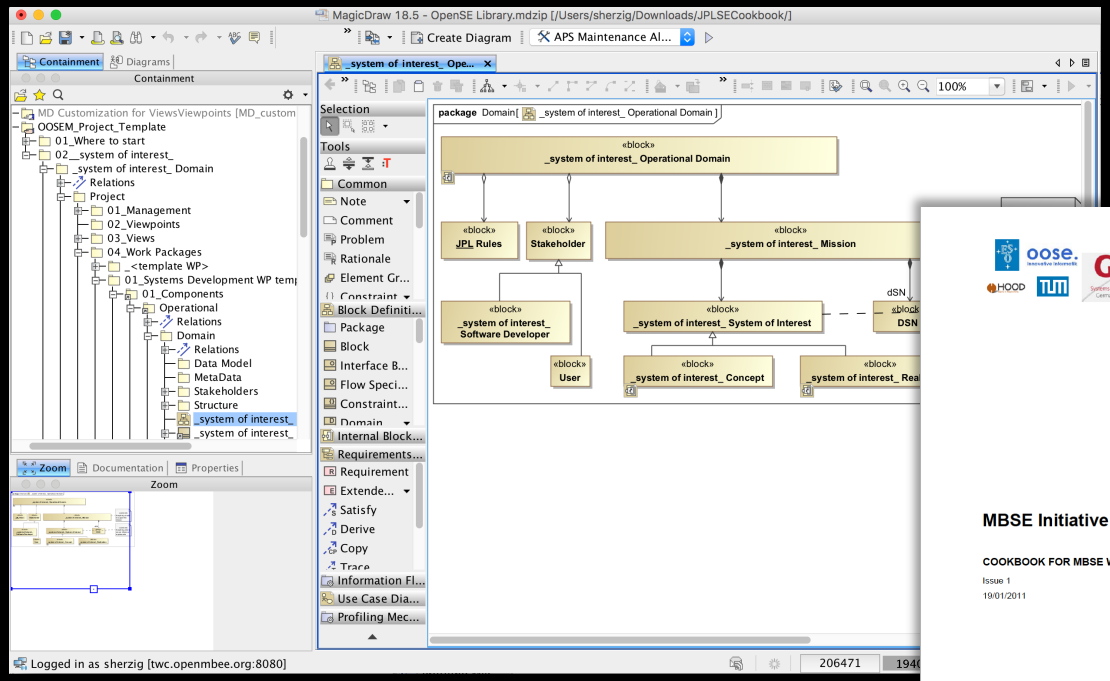

- CAE Project Systems Engineer at NASA's JPL - USA
- Member of INCOSE
- Co-Chair of the OMG SysML Revision Task Force
- Formerly Control System/Software Engineer and Architect at:
  - European Southern Observatory – Germany, Chile
  - CERN – Switzerland/France
  - Siemens Healthcare - Austria
- M.Sc. Computer Science (Austria)

# OpenSE Cookbook promotes re-use

- OpenSE Cookbook contributes to JPL institutional and project specific Cookbooks
- Project-independent modeling patterns as guidelines
- Project-specific modeling patterns for common modeling tasks

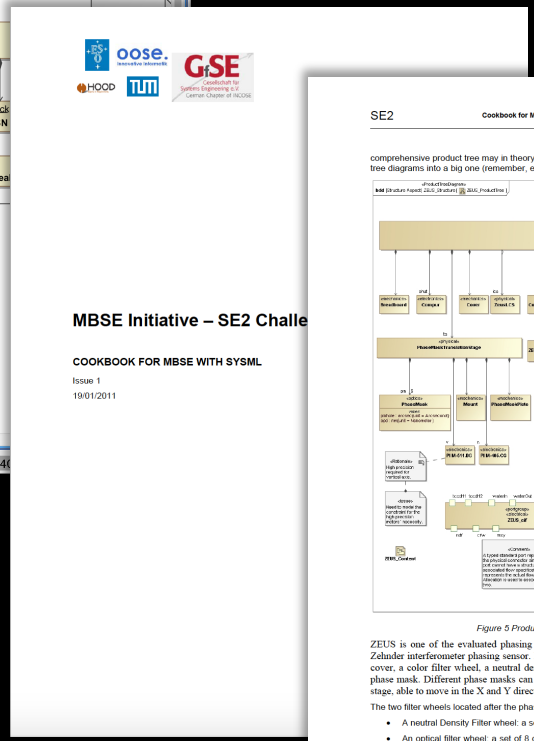


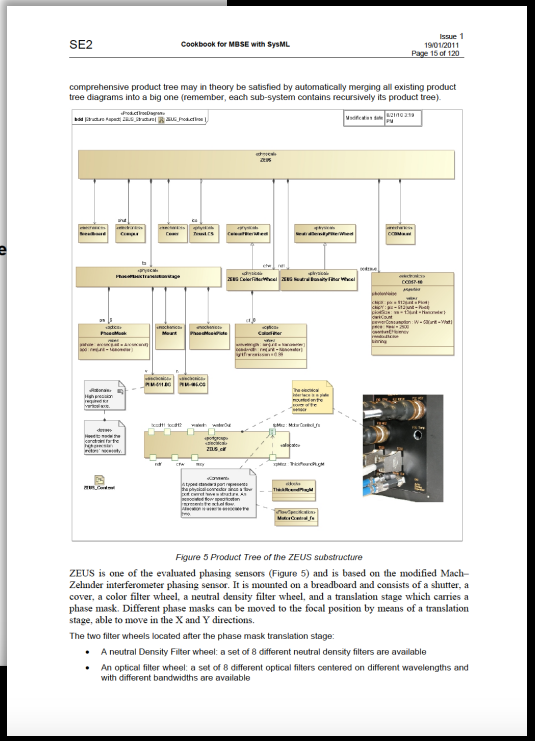
# OpenSE Cookbook and Template Model




"Cookbook" for modeling methodology & patterns

Template models to be used by projects as a starting point, with recommended organization, model libraries, etc.

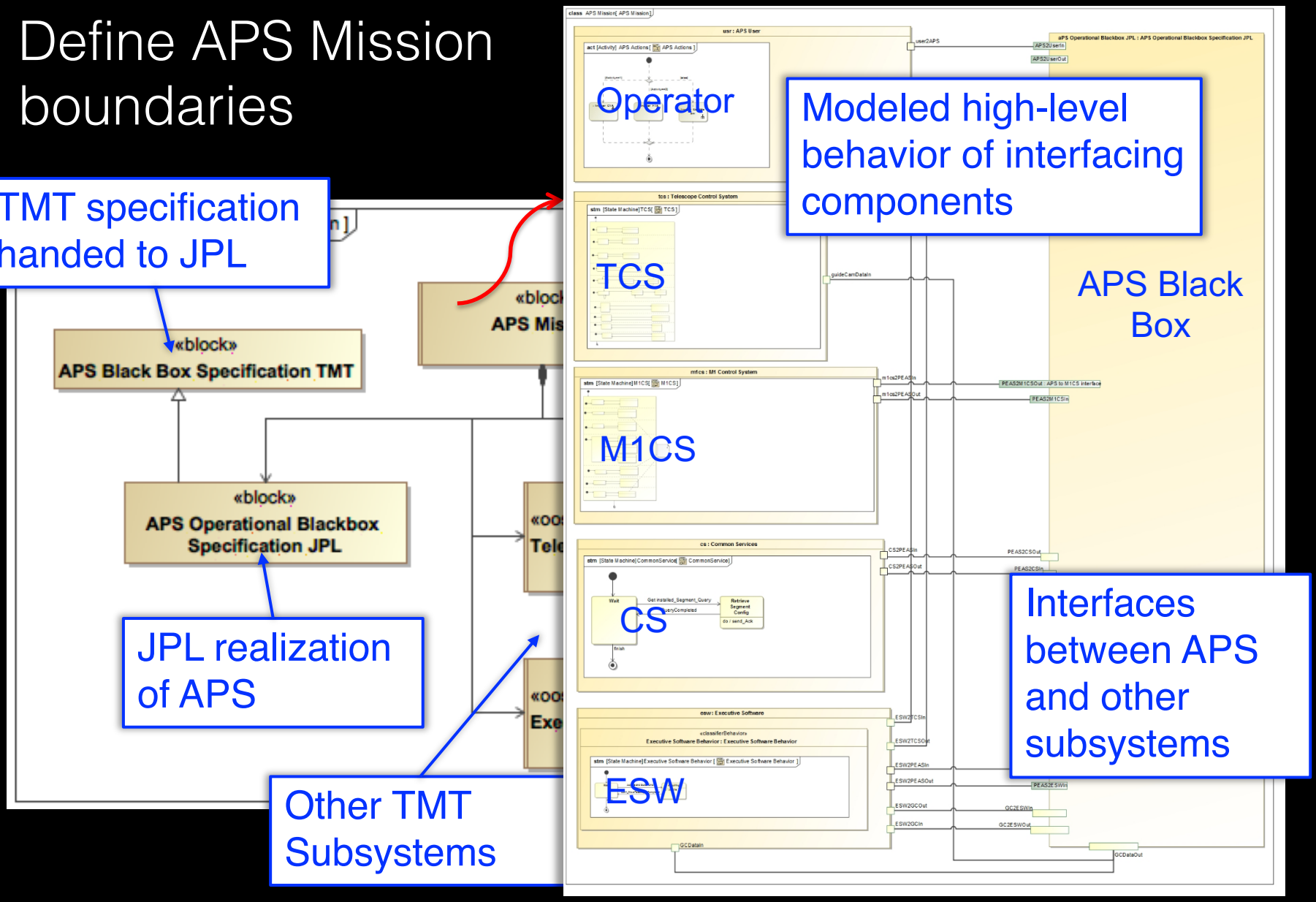


# OpenSE Cookbook is used as reference

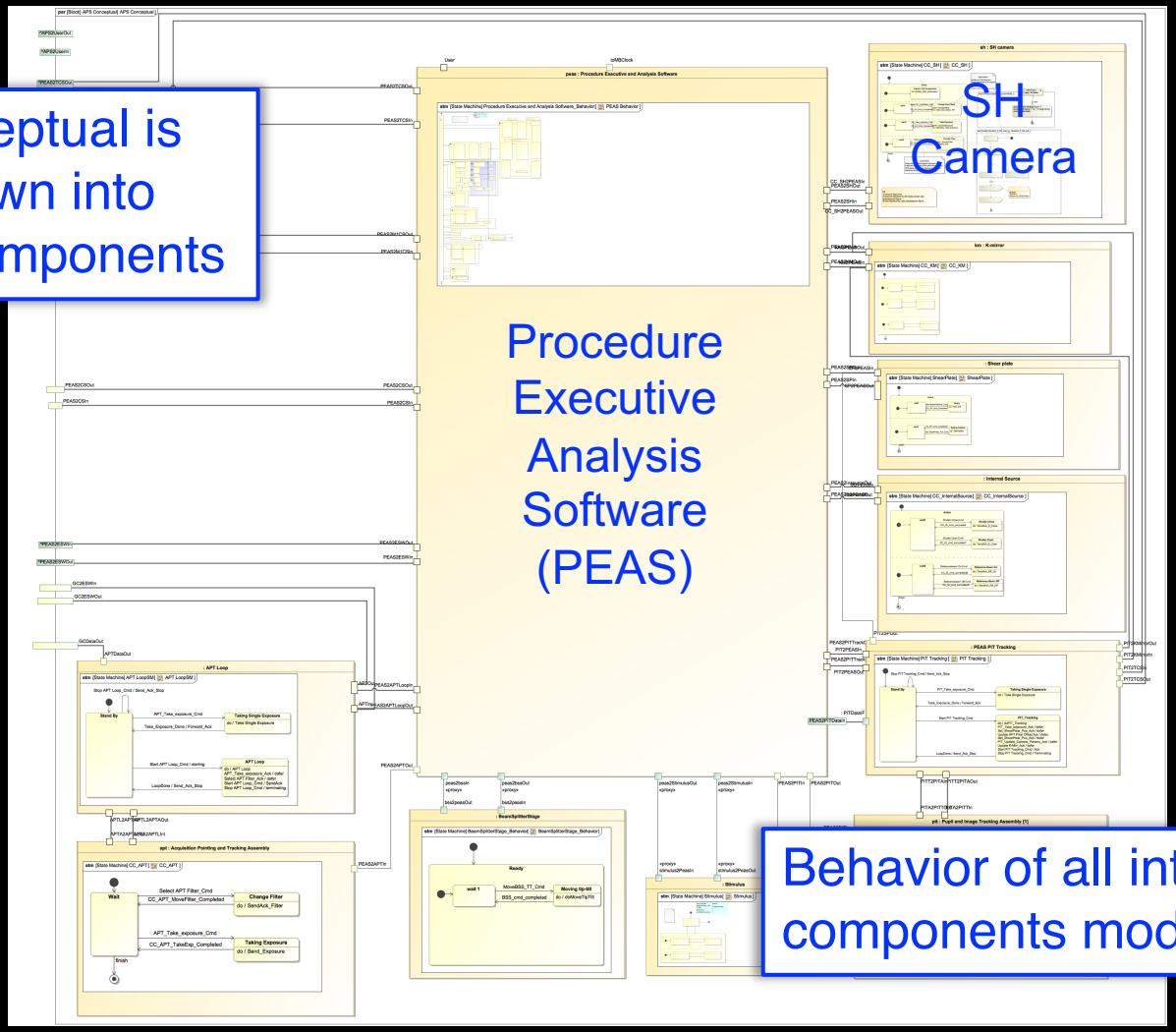
- OpenSE cookbook and TMT model used as reference model for the OMG SysML 2 standard
  - Demonstrate how SysML 2 will improve, simplify, change model wrt SysML 1.x
- Training material and knowledge transfer
- Promote standards and conventions
- Used by vendors as reference to test and evolve products

# Define APS Mission boundaries



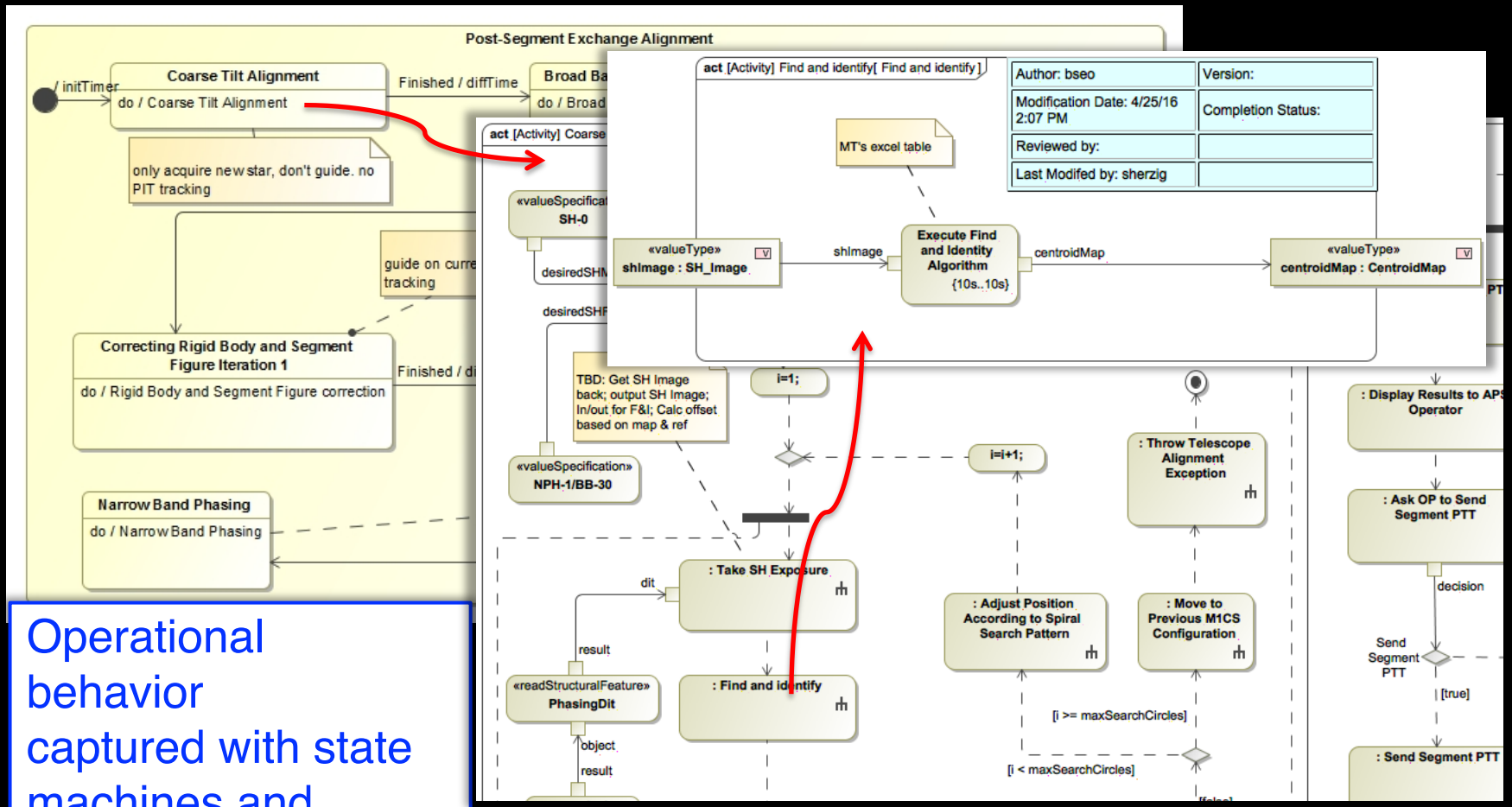
# Elaborate Conceptual Architecture

APS conceptual is broken down into several components



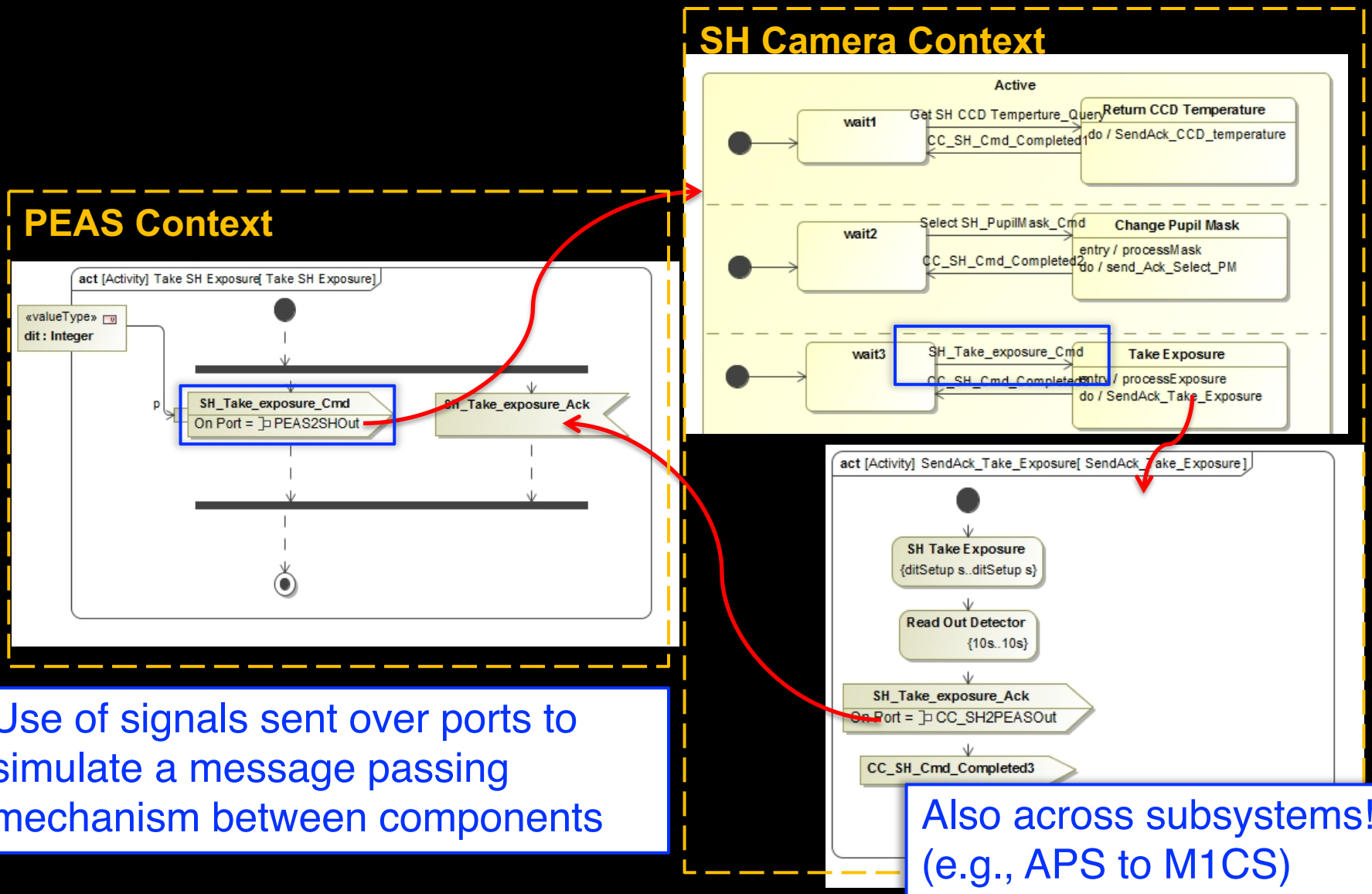

Behavior of all interacting components modeled

# Capture Component Behavior and Characteristics




Operational behavior captured with state machines and activity models

# Specify Interactions Between Components

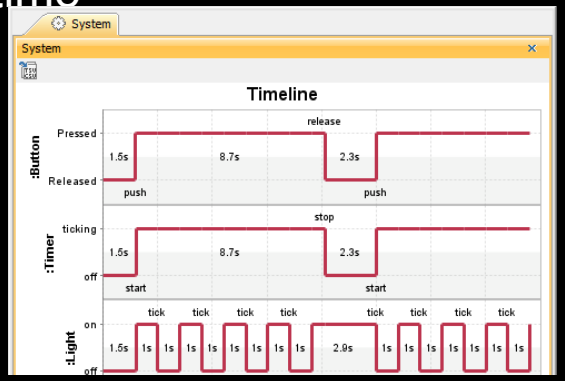


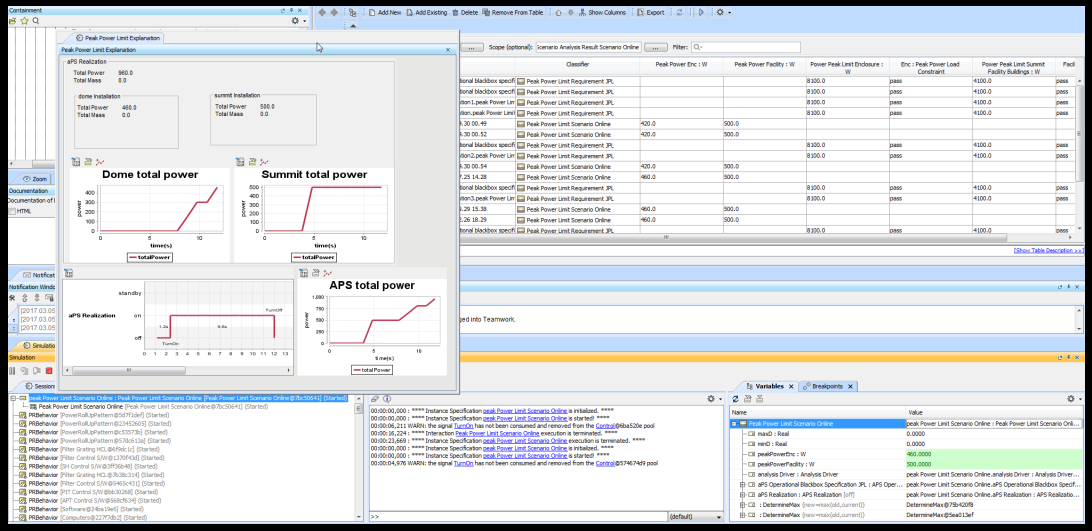

Use of signals sent over ports to simulate a message passing mechanism between components

Also across subsystems! (e.g., APS to M1CS)

# Run Analyses

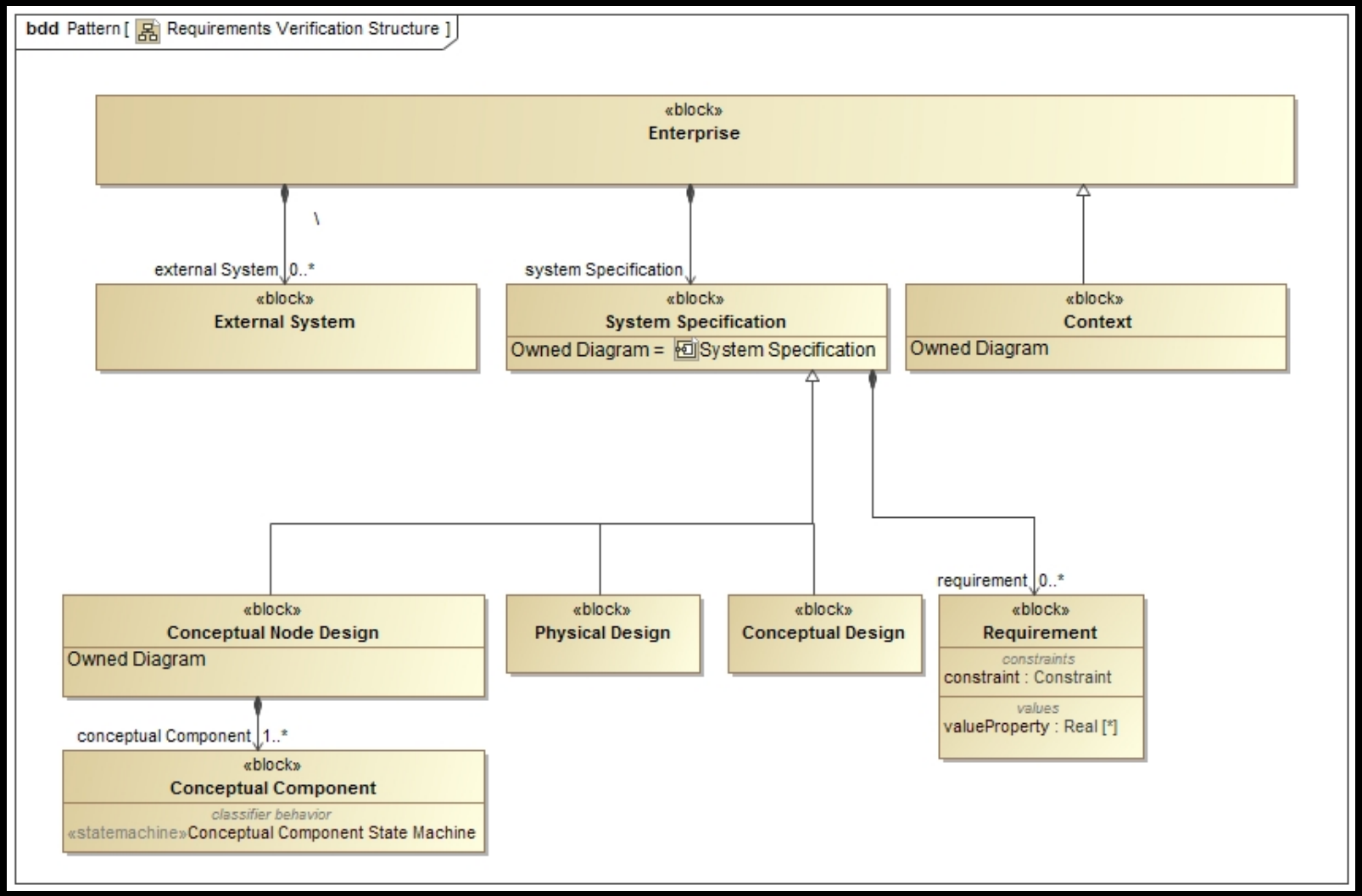
- Run a configured analysis with a simulation engine on the initial conditions to get the final conditions
- Produce the analyses declaratively, repeatably (in any system), without a single line of project-specific code -> reducing time and resources
- Produce the following views on final conditions
  - **Table** showing final analysis values (e.g. peak power) and the constraint's pass/fail status for each scenario
  - **Timelines**: state changes for components over time
  - **Value profiles**: total rolled up values over time



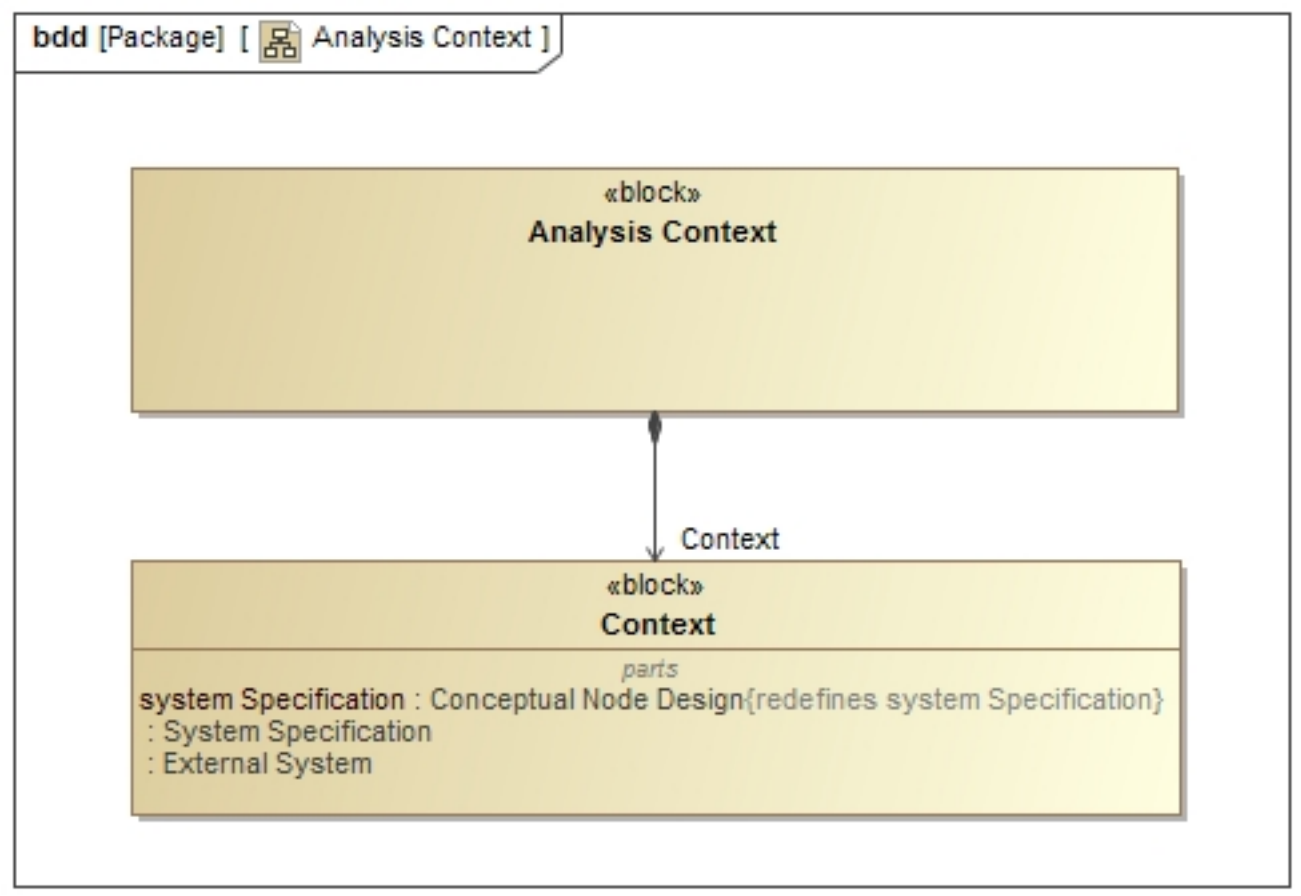




| # | Name | Classifier | T Final : Real | Ph |
|---|---|---|---|---|
| 1 | calibrations Duration S | Calibrations Duration S | | |
| 2 | calibrations Duration S | APS Conceptual | | |
| 3 | calibrations Duration S | Procedure Executive ar | 8466.0 | 11 |

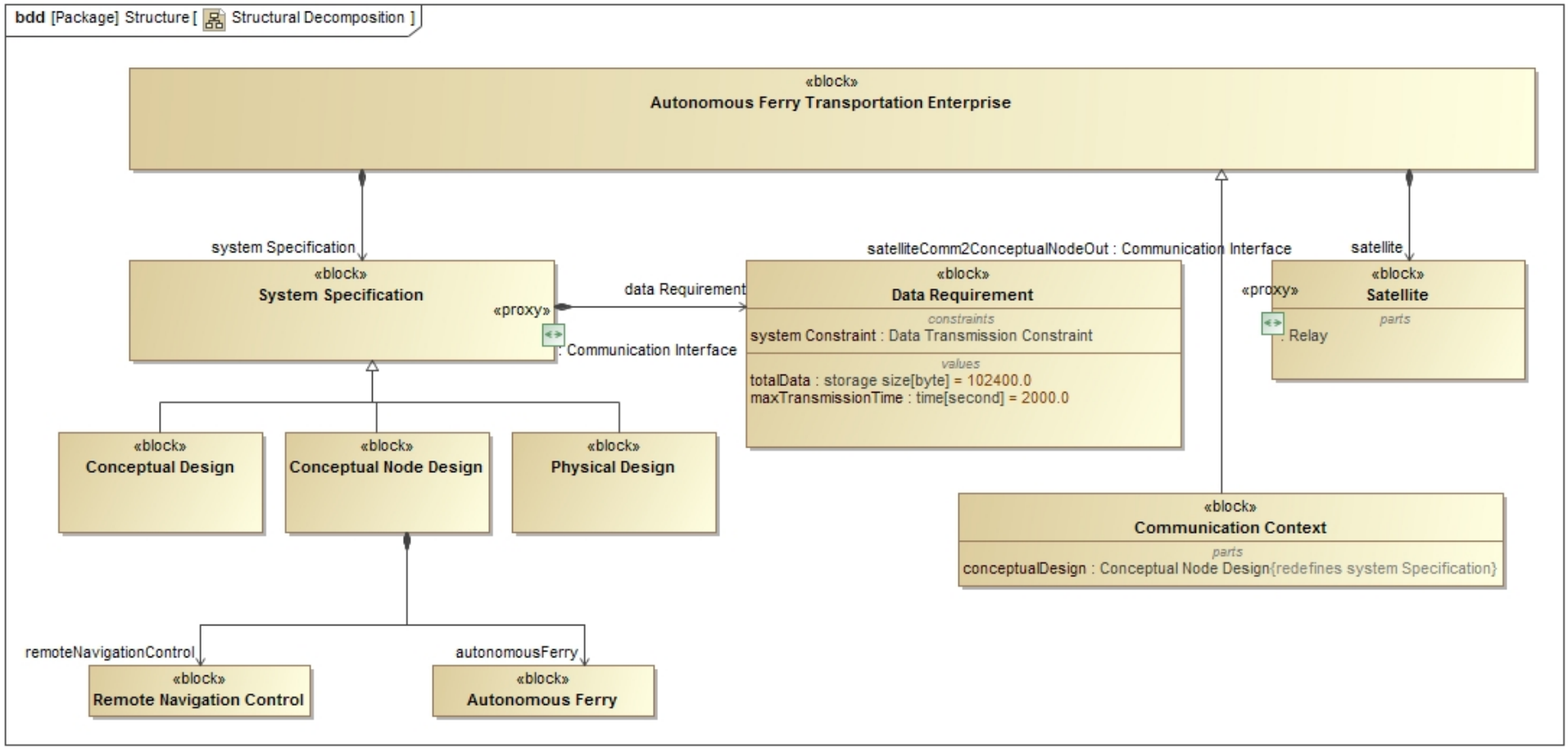
# System Context



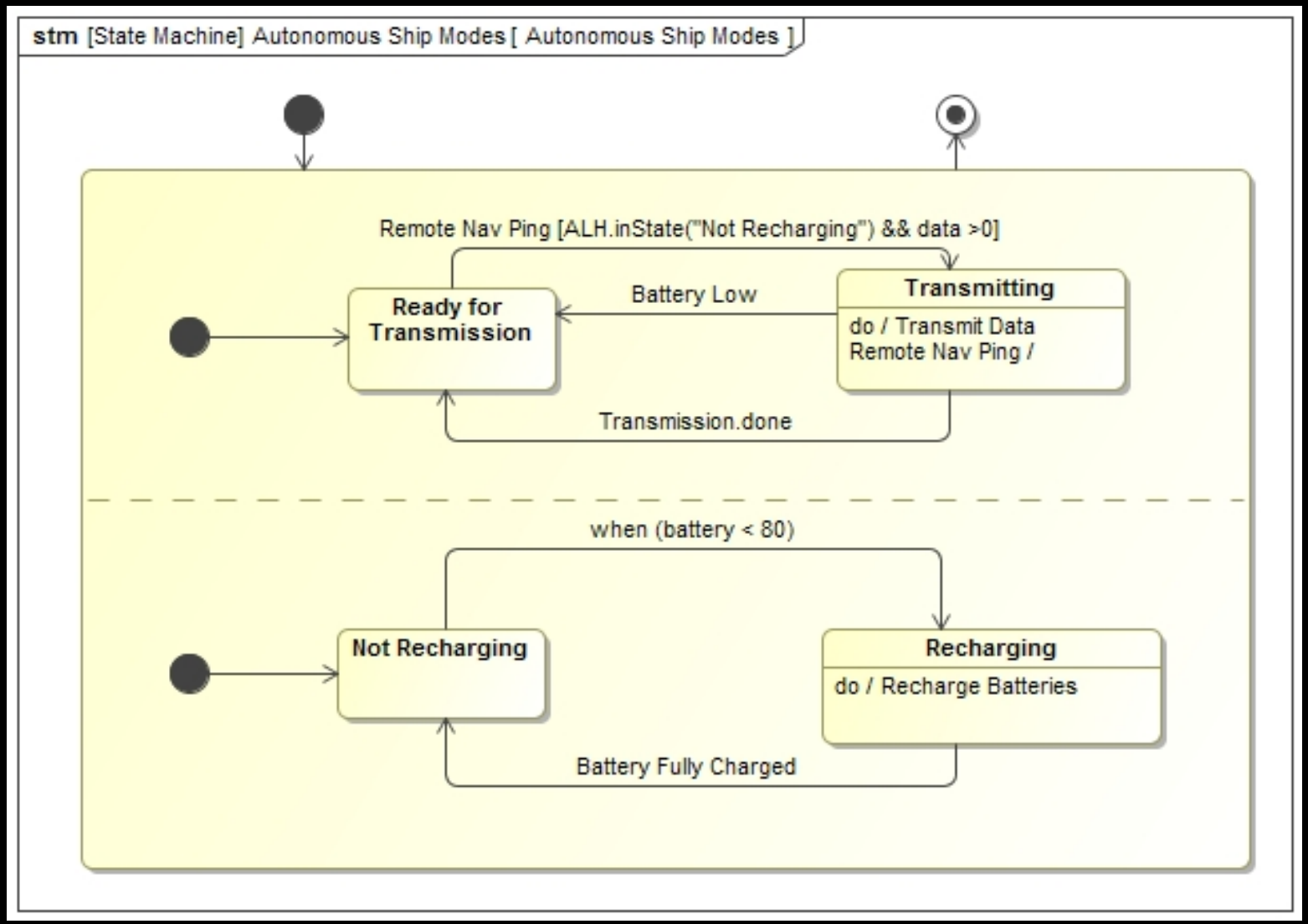
# Analysis Context



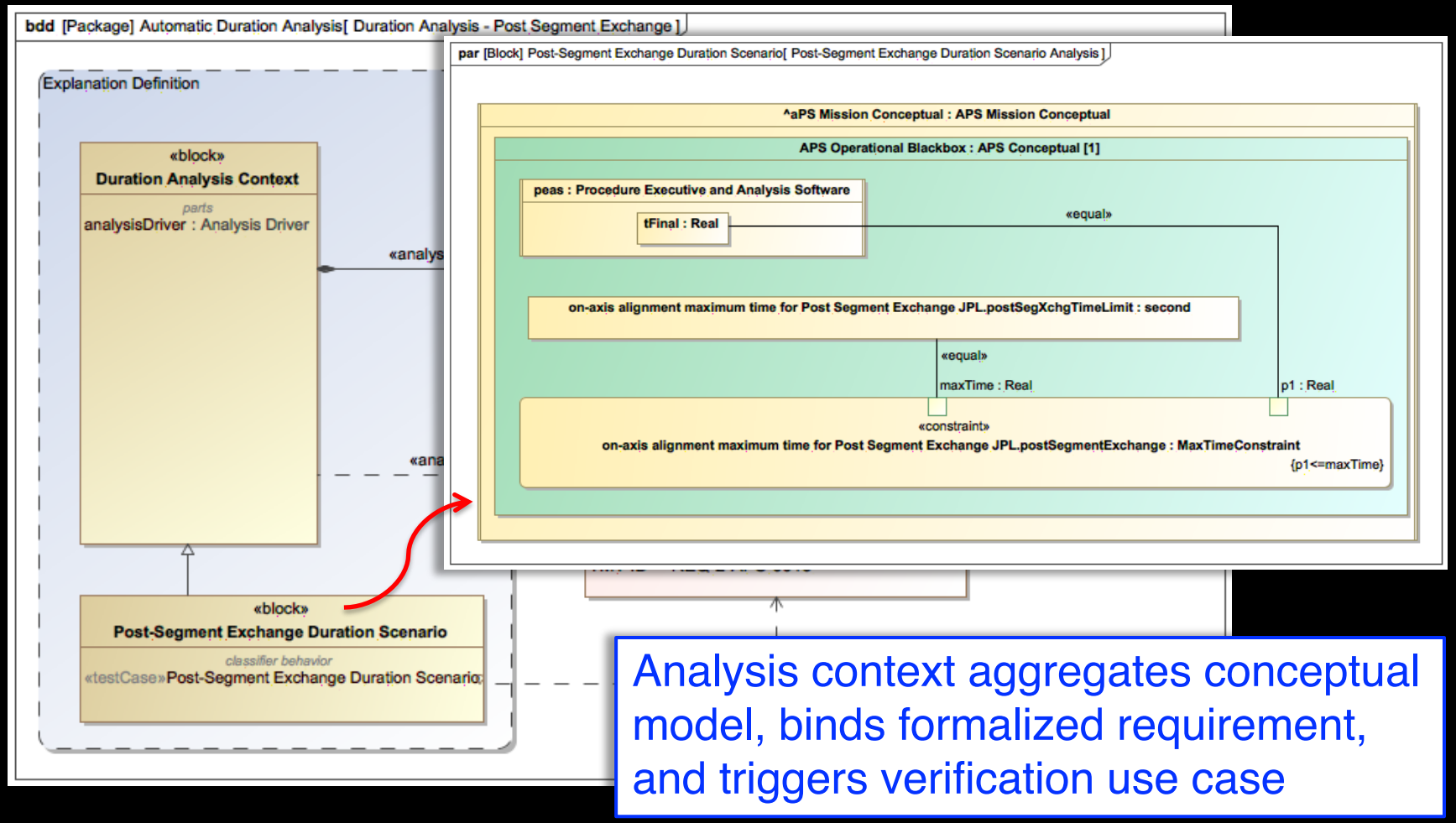
# Context Educational Example



# Behavior Ship

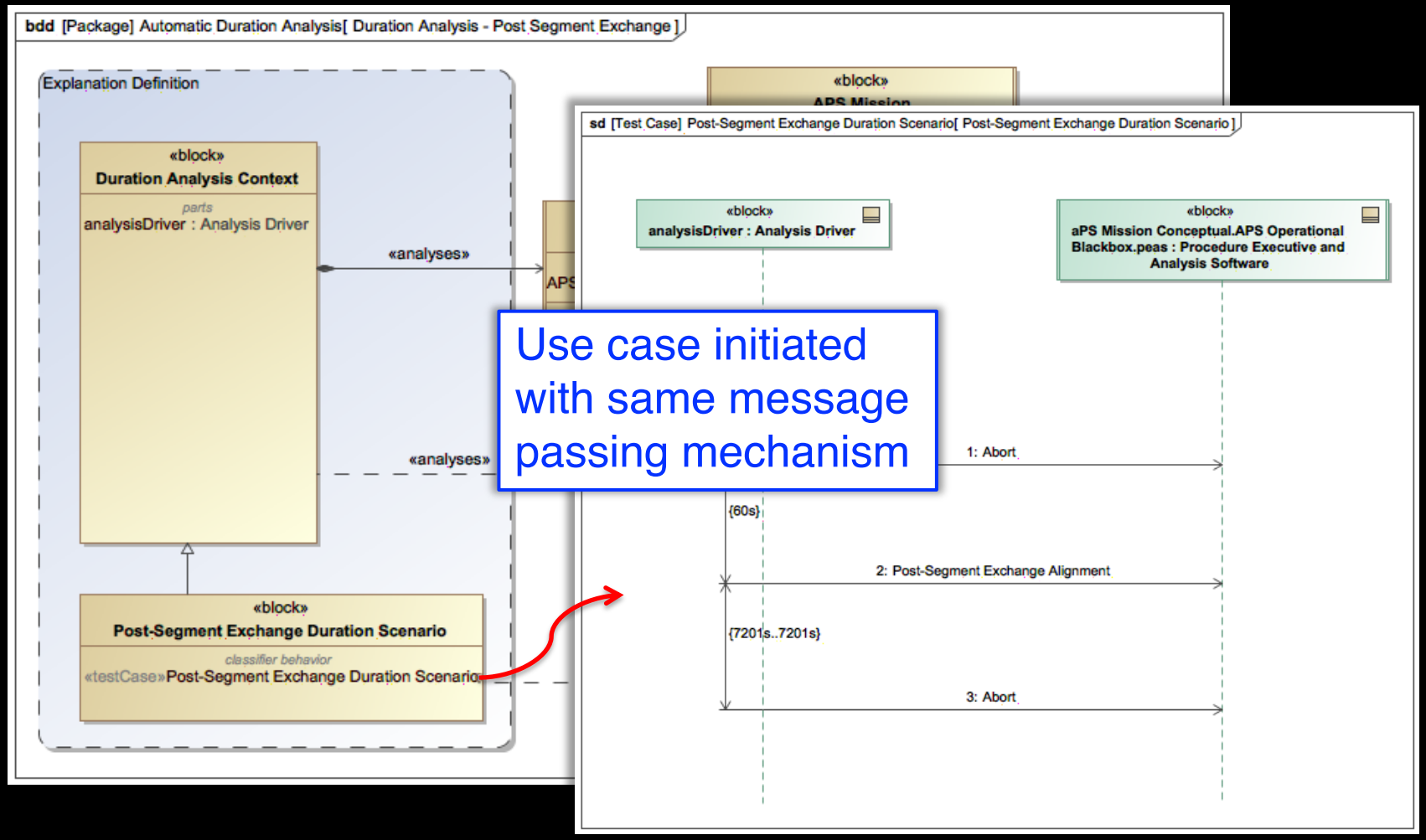


# Verifying Timing Requirements by Simulation




Analysis context aggregates conceptual model, binds formalized requirement, and triggers verification use case

# Verifying Timing Requirements by Simulation



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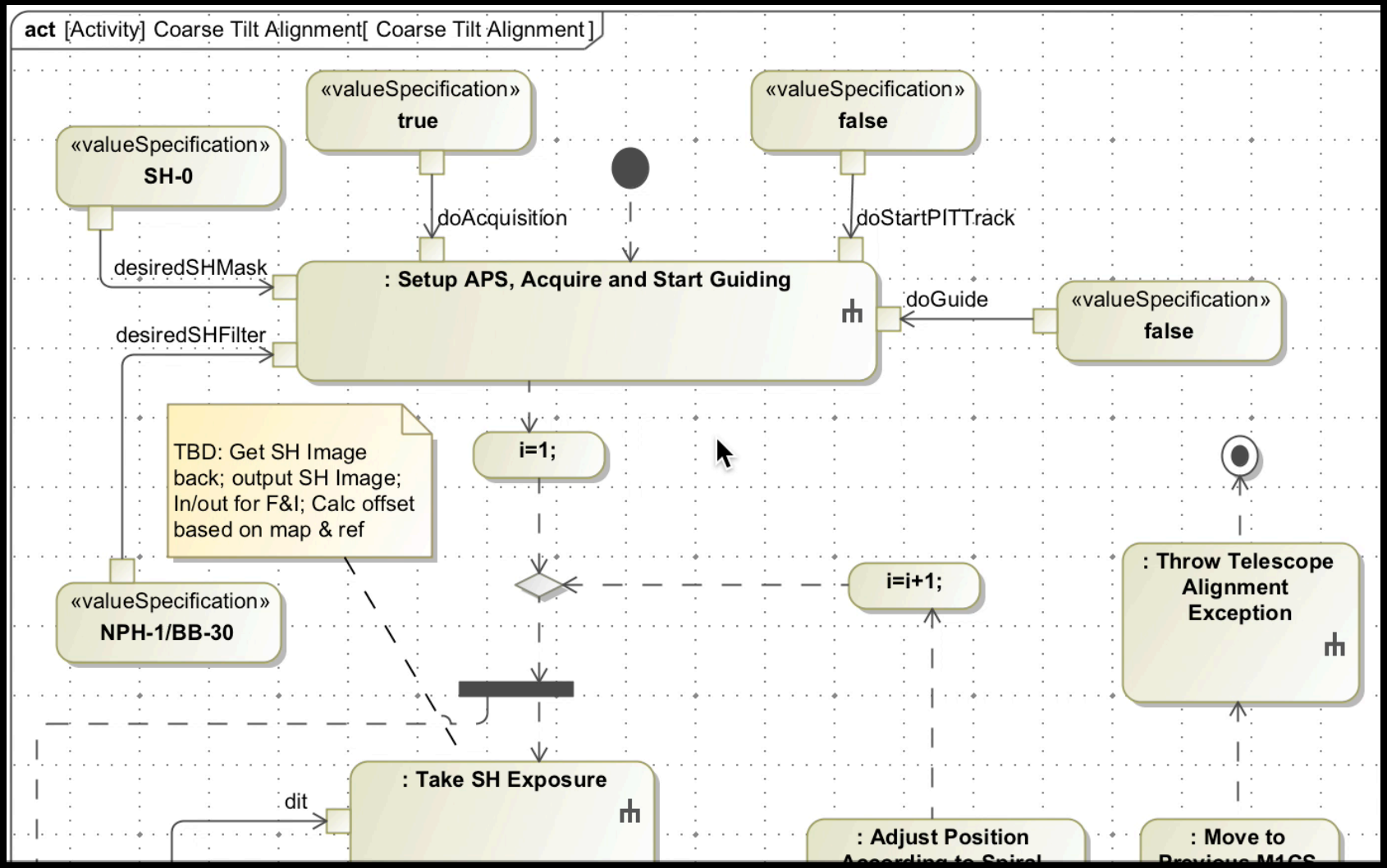
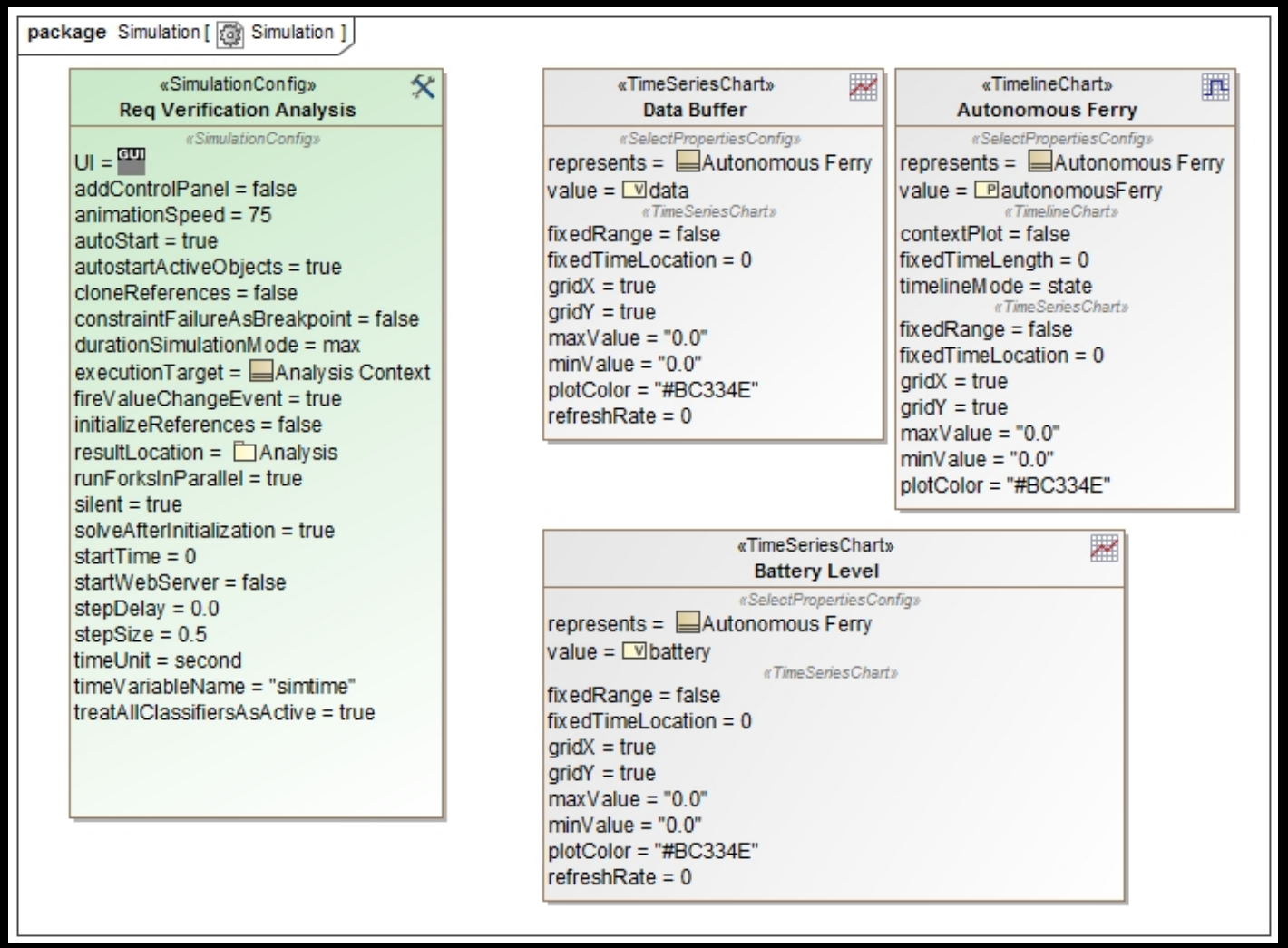
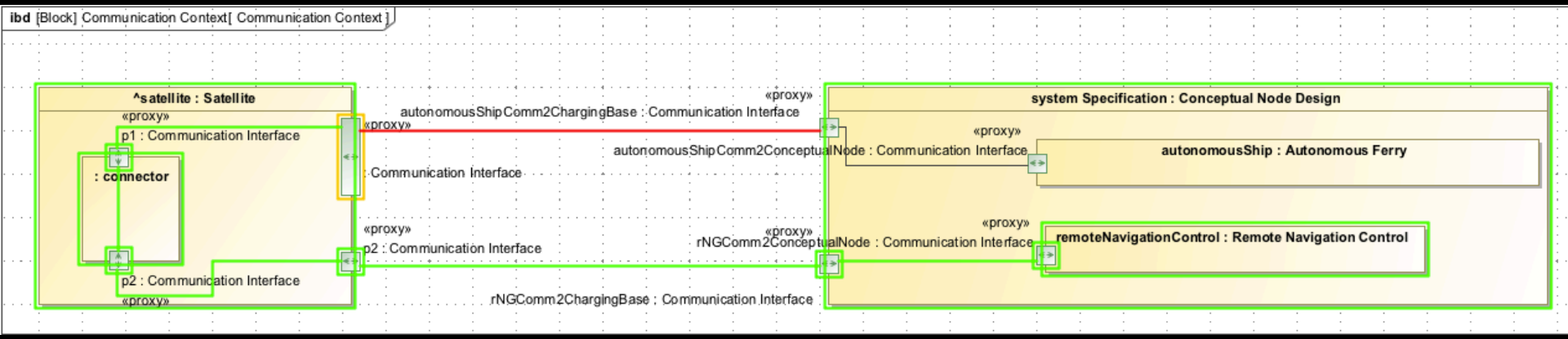


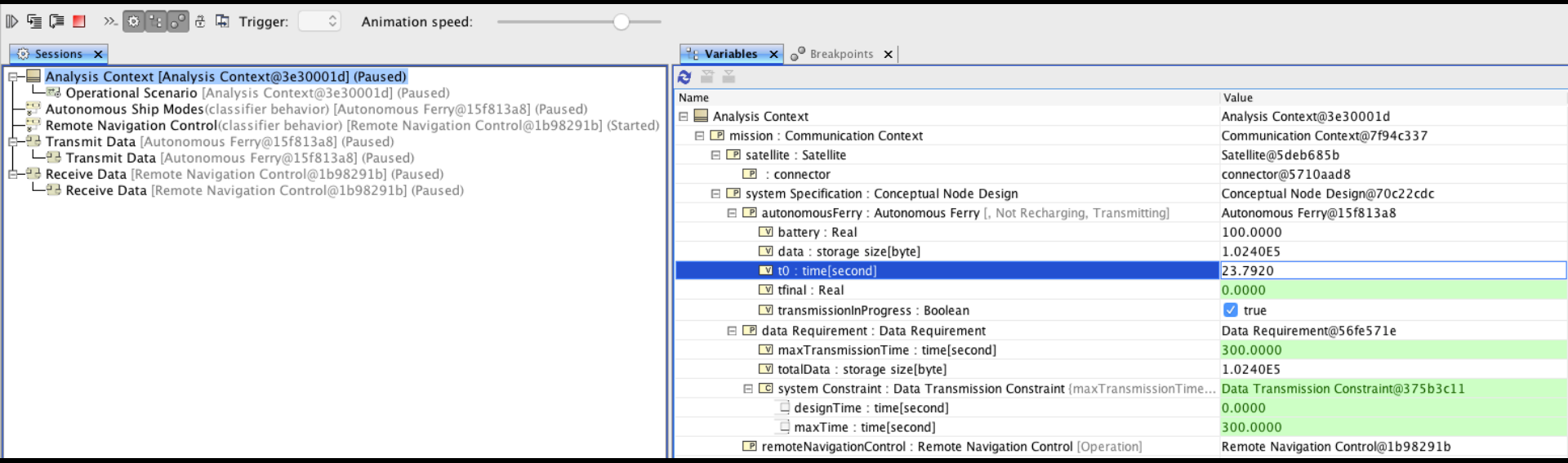
# Simulation Configuration with Cameo



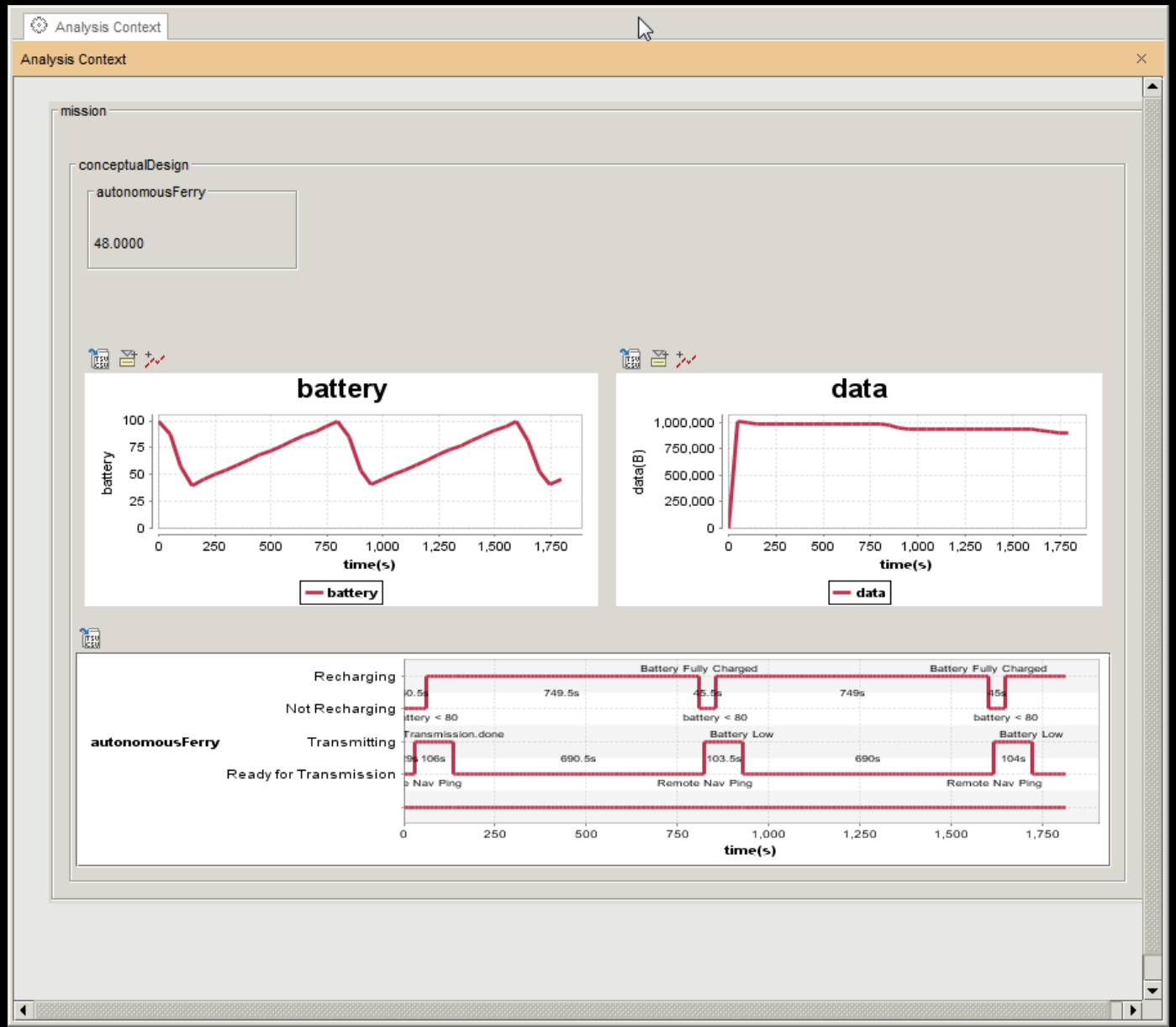
# Executing a scenario



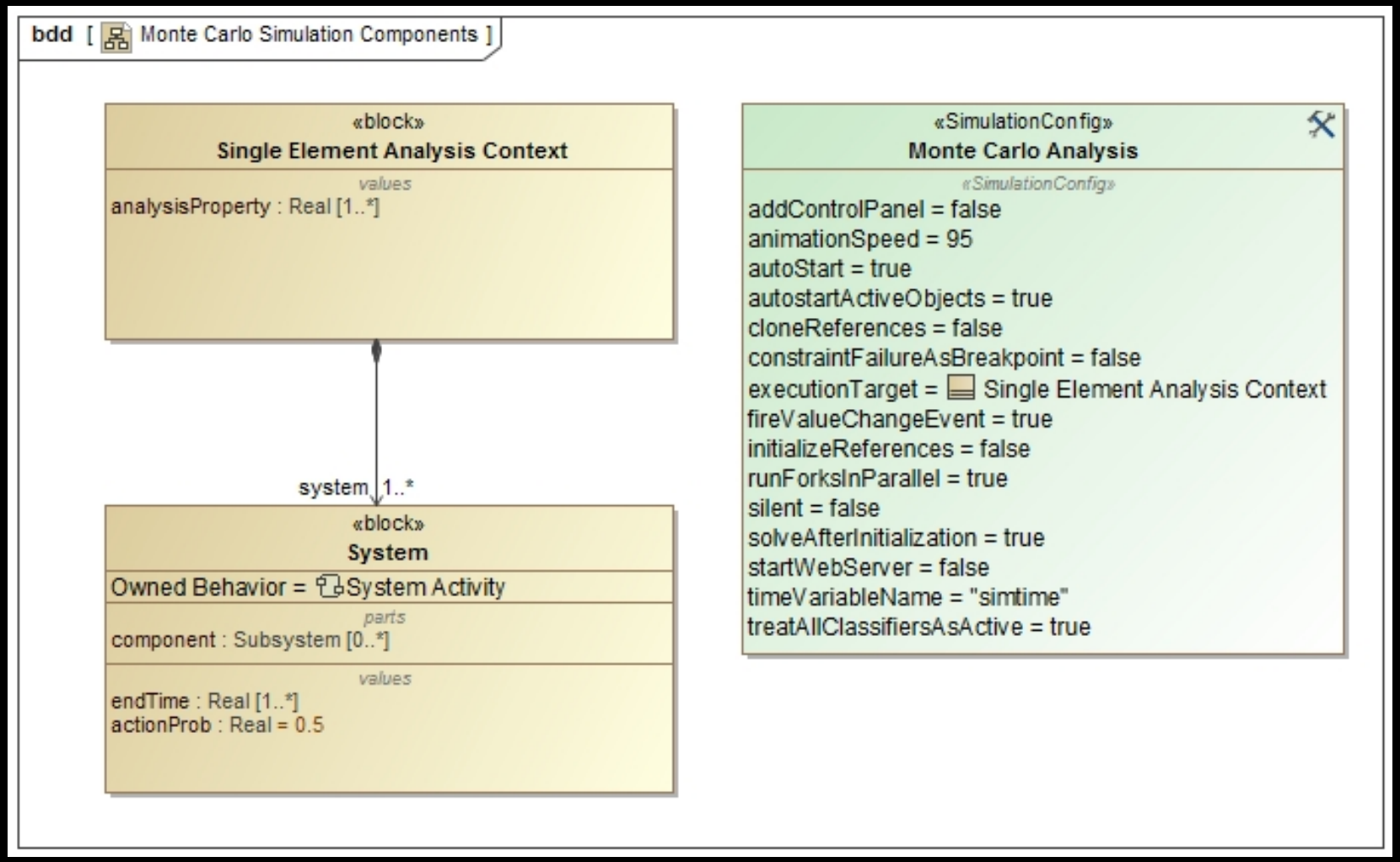
# Simulation Run



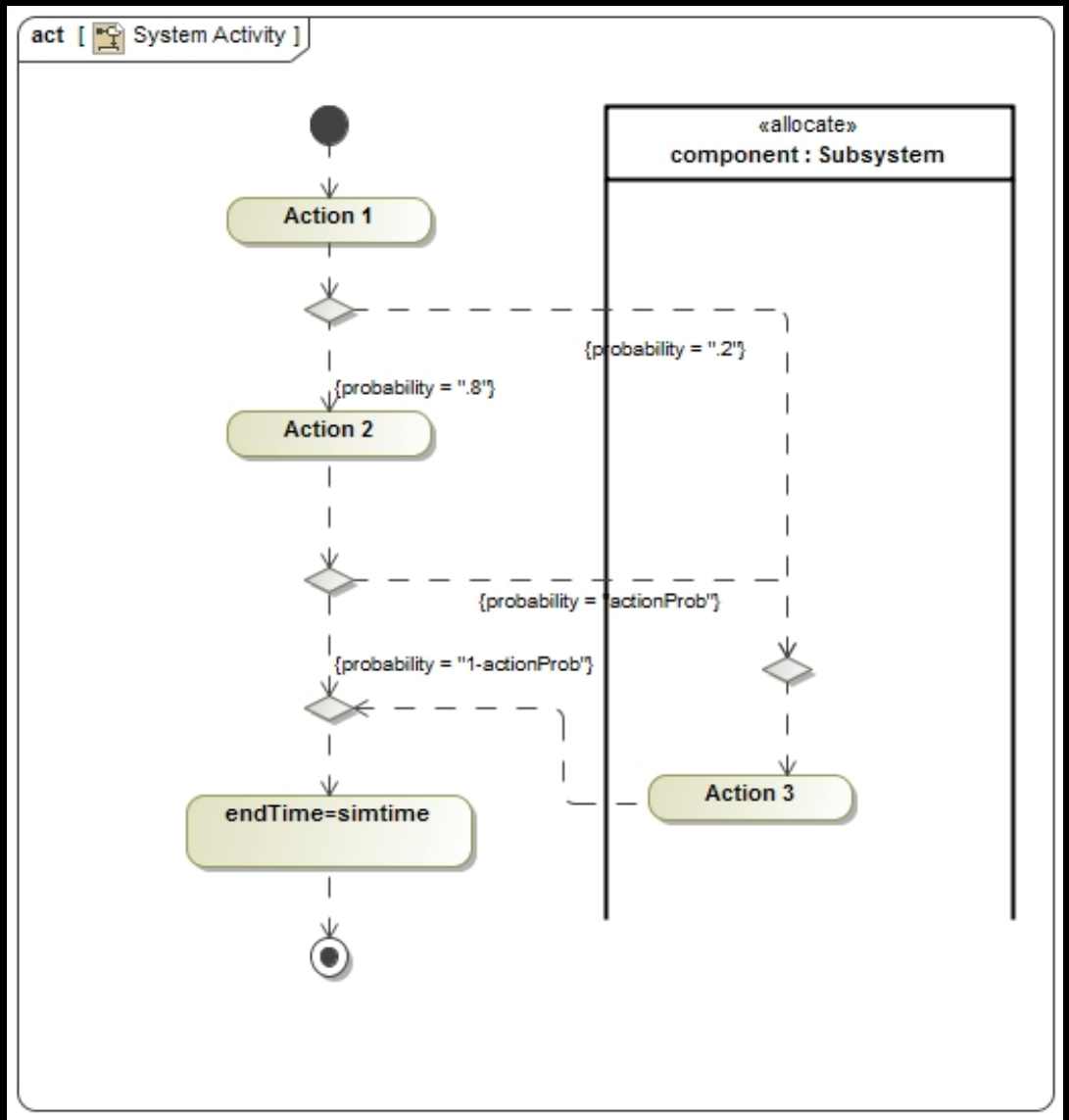
# Analysis by Simulation



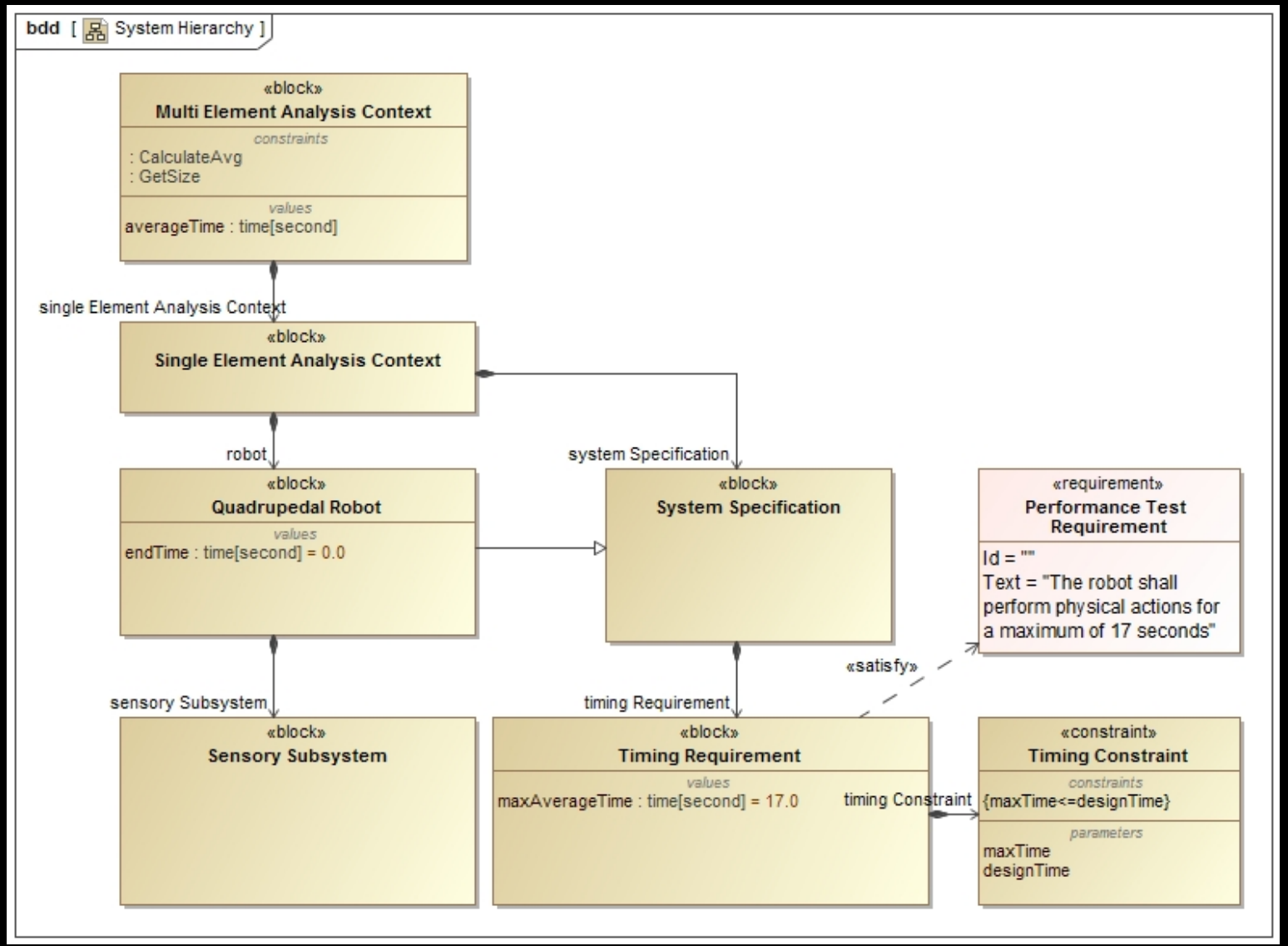
# Single Element Analysis Context



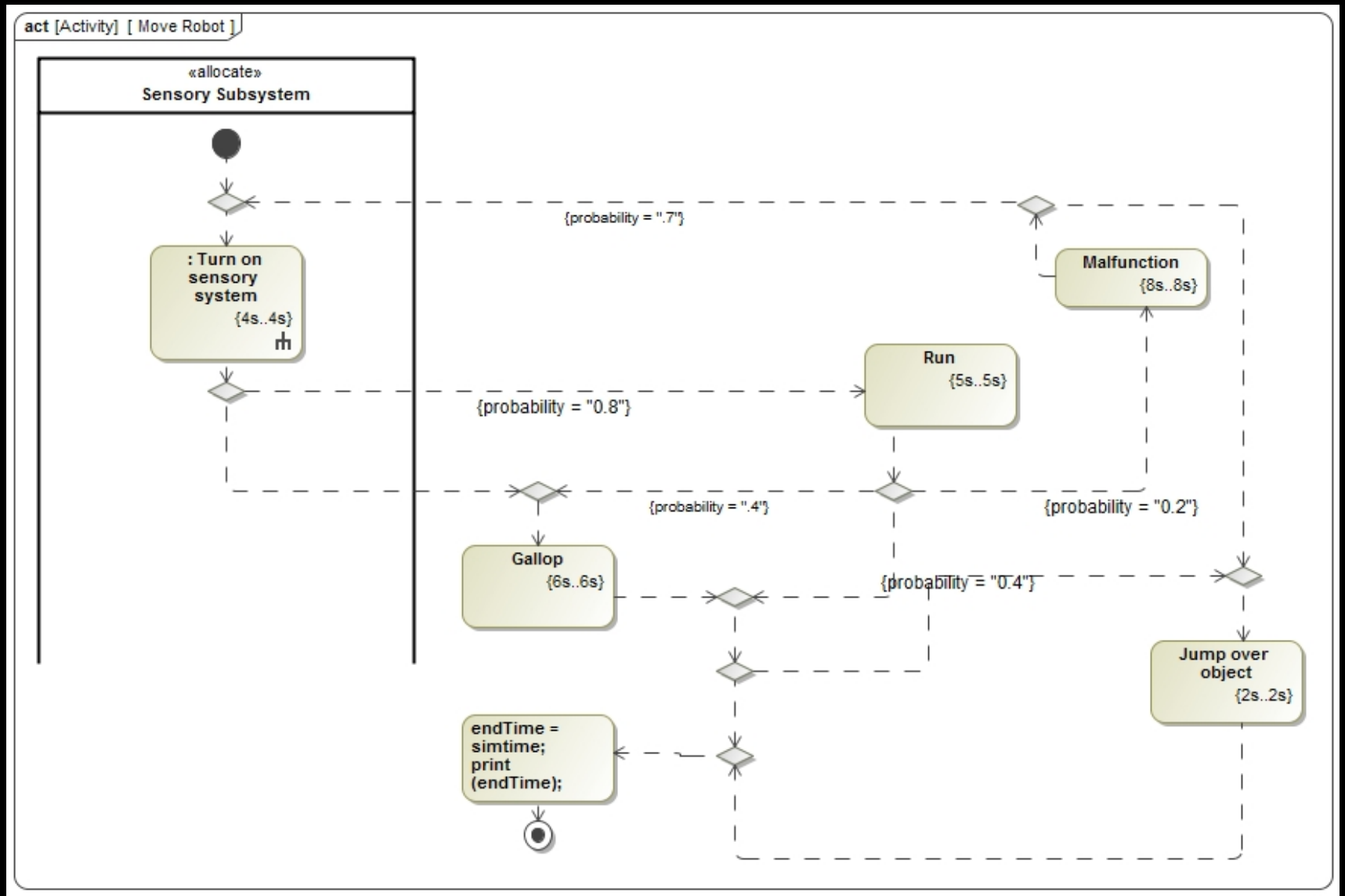
# Behavior with Probablity



# Example Quadrupedal Robot



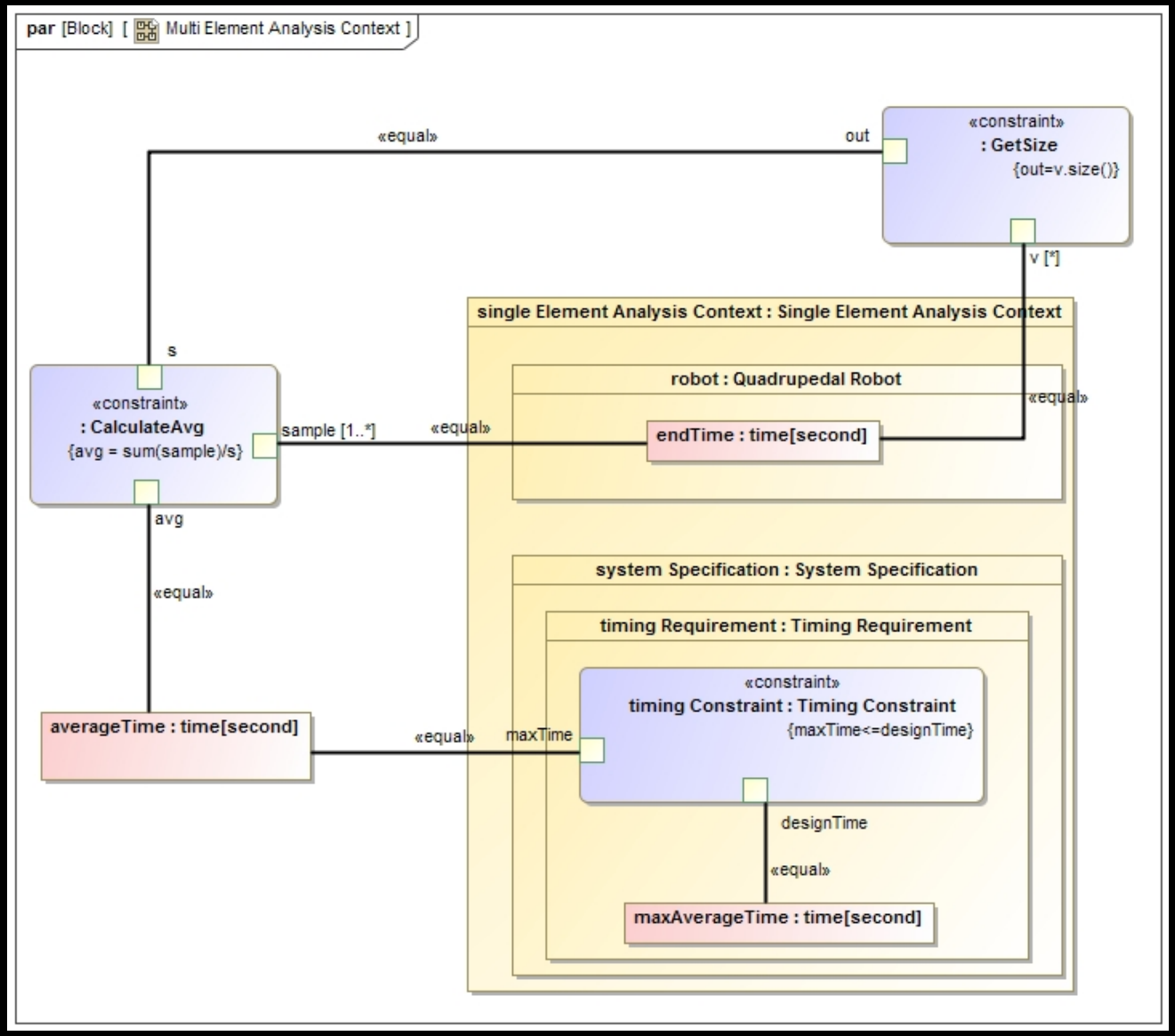
# Behavior with probability



# Individual Results

| # | Name | endTime : time[second] |
|---|---|---|
| 1 | robot at 2017.07.20 17.38 | 10.0 |
| 2 | robot at 2017.07.20 17.38 | 12.0 |
| 3 | robot at 2017.07.20 17.38 | 15.0 |
| 4 | robot at 2017.07.20 17.38 | 12.0 |
| 5 | robot at 2017.07.20 17.38 | 17.0 |

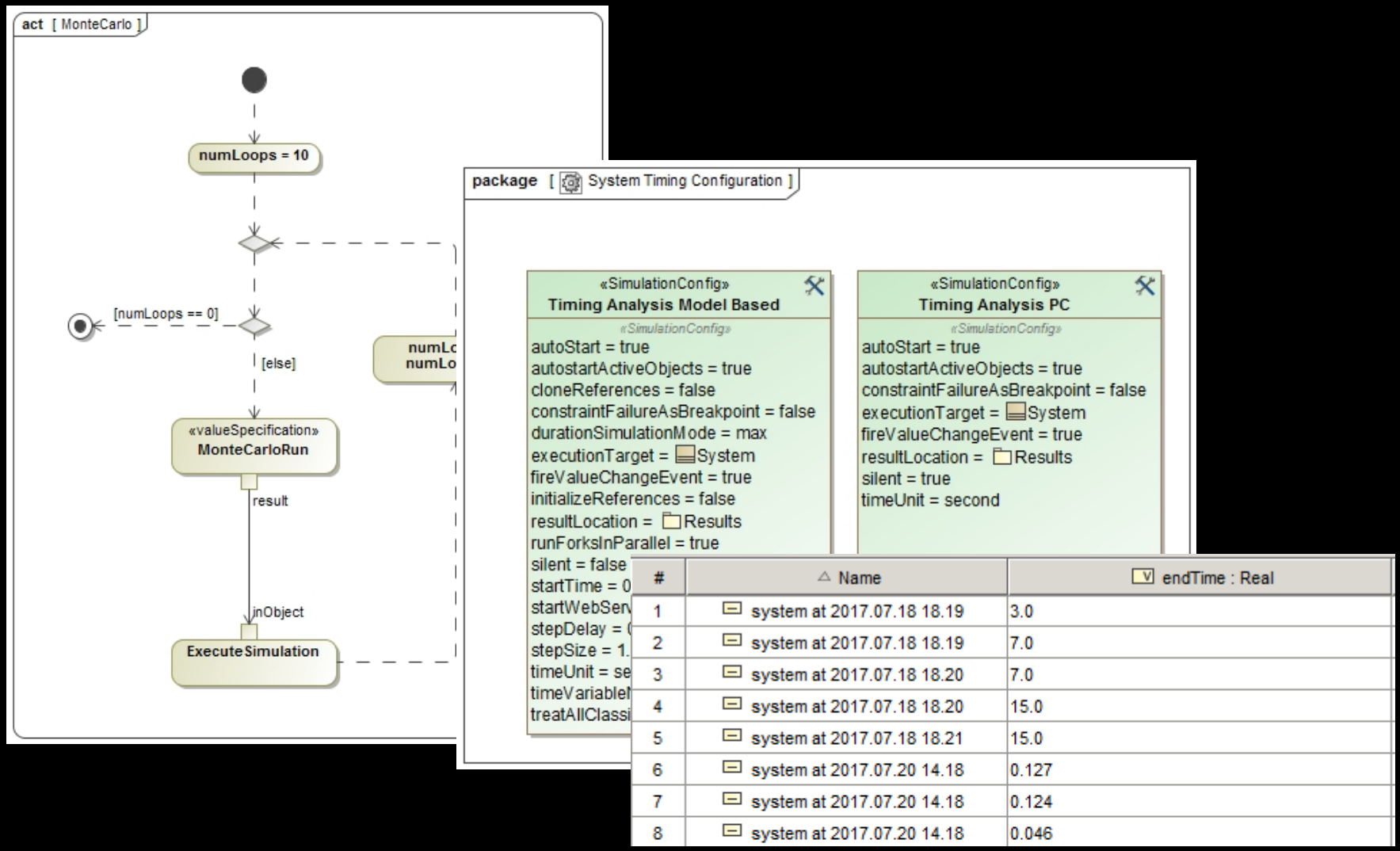
# Analysis Context



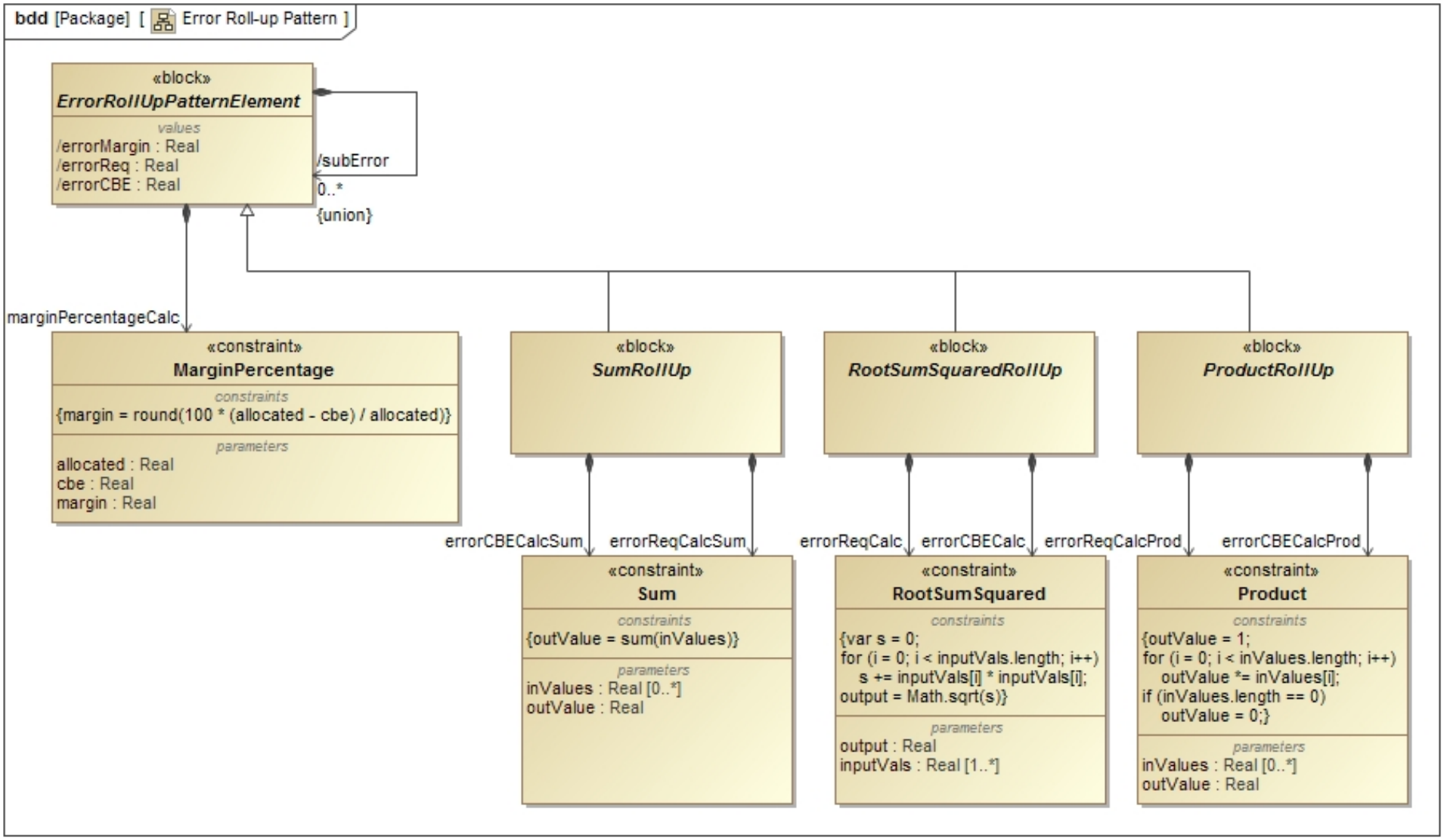
# Analysis Result

| # | Name | system Specification.timing Requirement.timing Constraint : Timing Constraint | robot.endTime : time[second] |
|---|---|---|---|
| 1 | single Element Analysis Context at 2017.07.28 11.32 | pass | 12.0 |

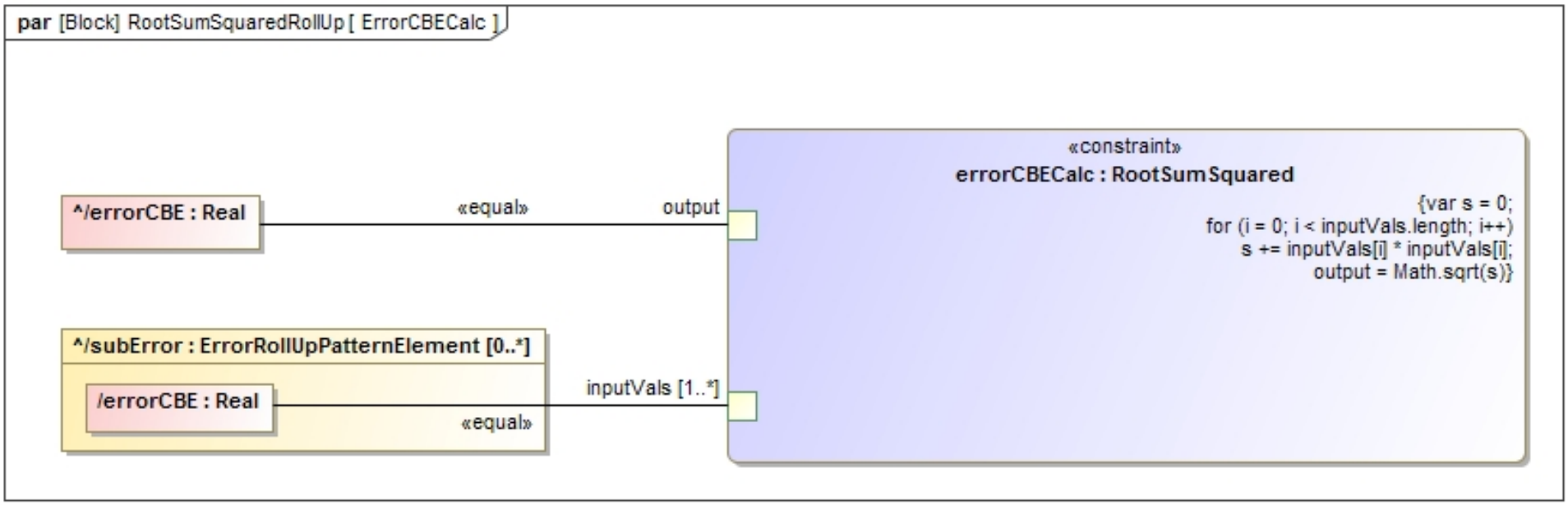
# Cameo Simulation Toolkit



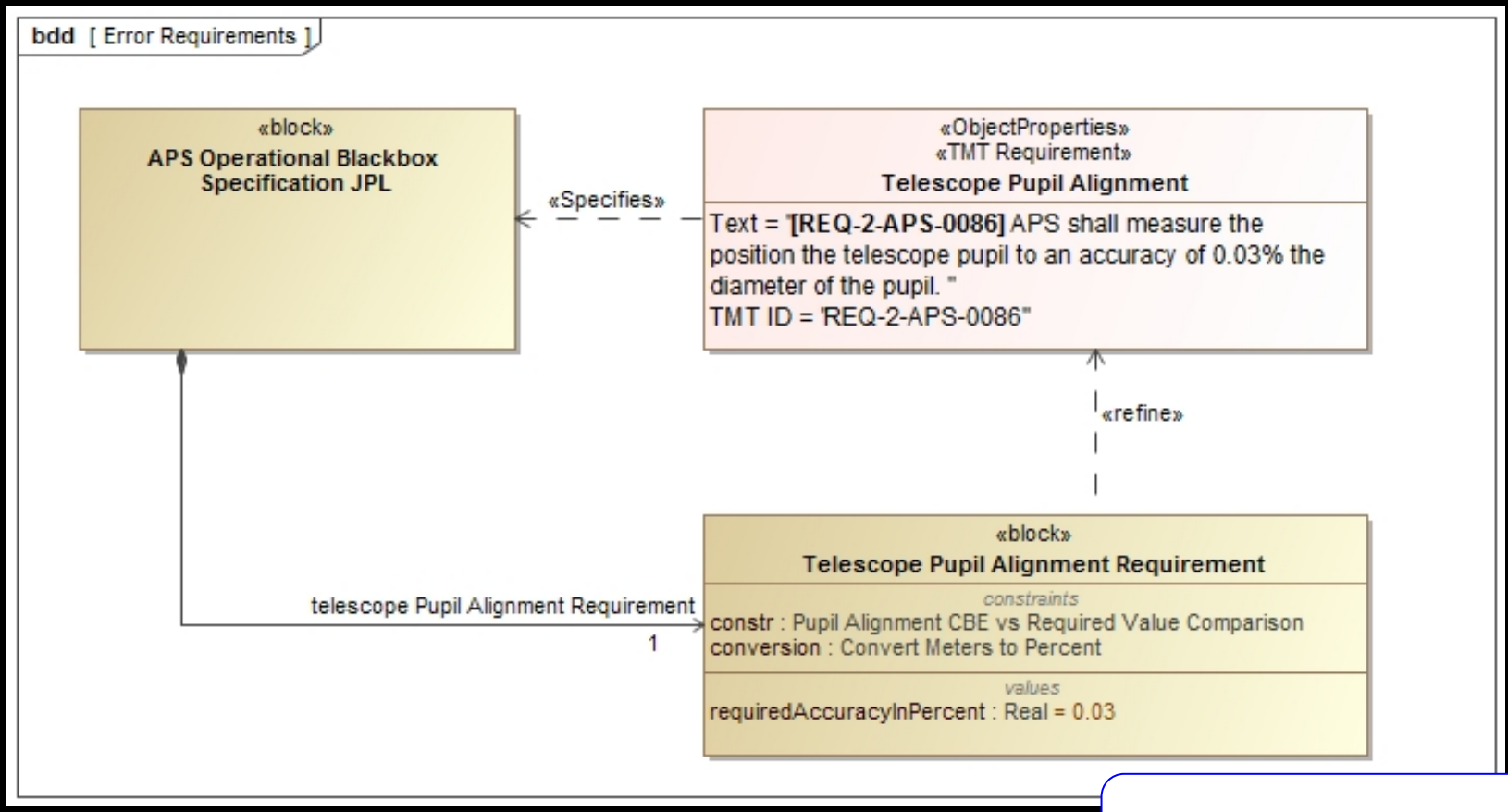
# Error Roll-up Pattern



# RSS Parametric Model

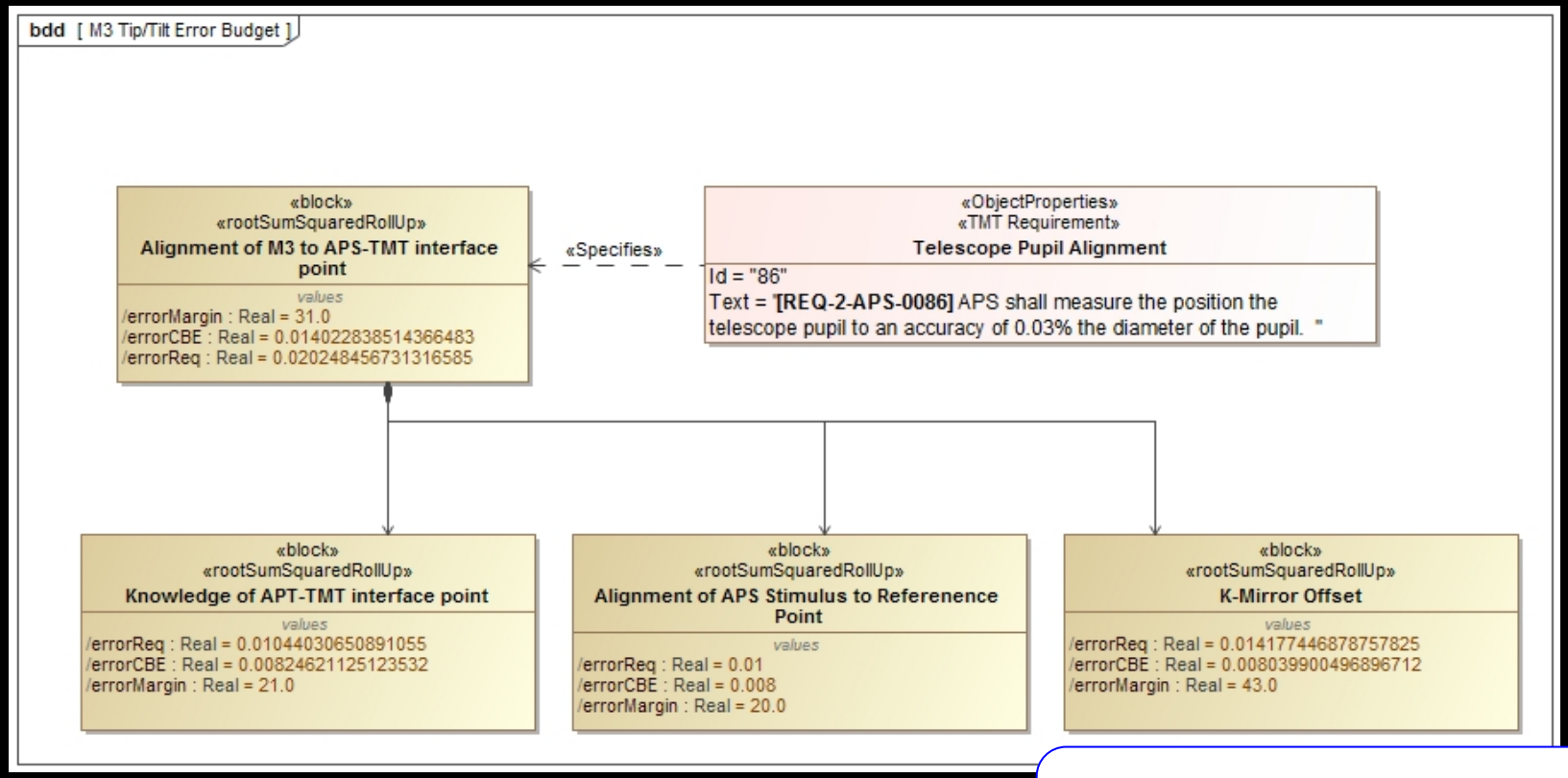


# APS - Alignment error of the M3 to APS interface




**Context**

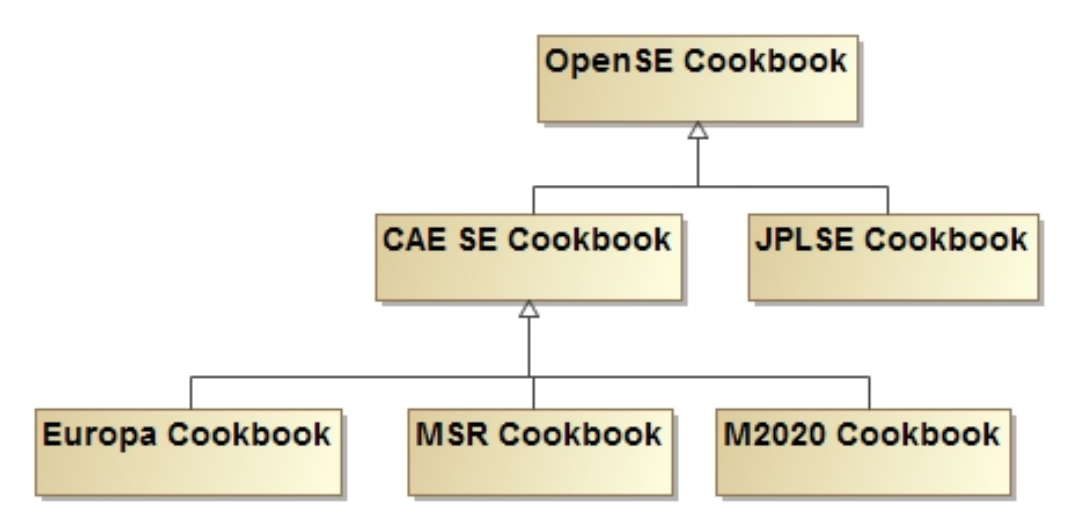
# Specify RSS Tree



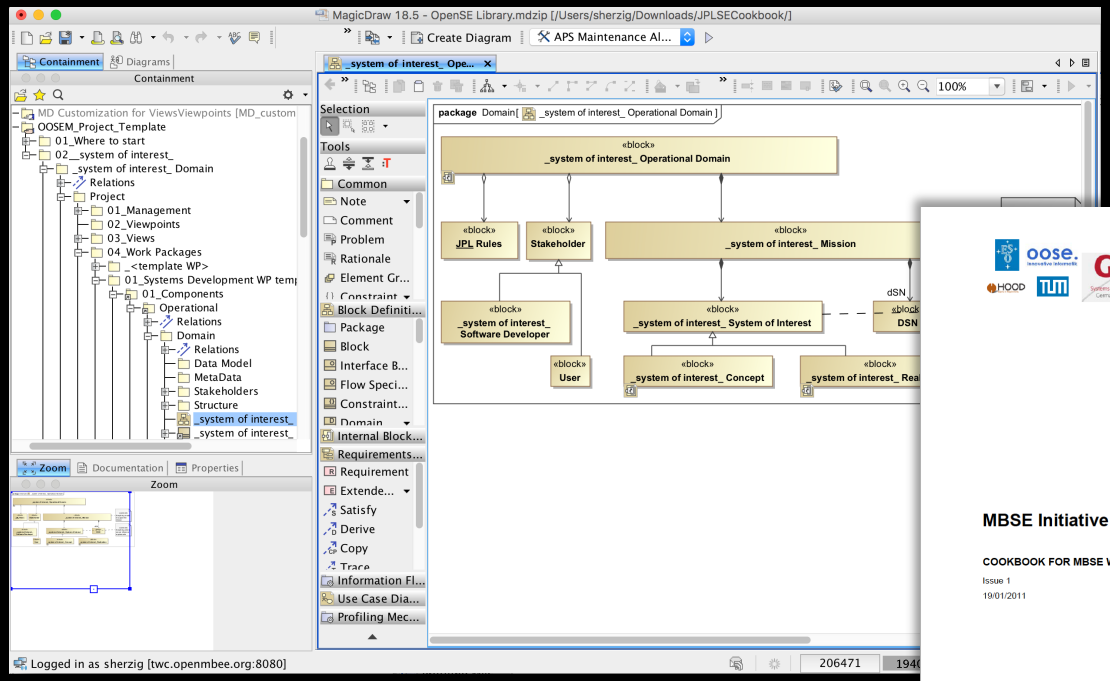

**Application of pattern**

# OpenSE Cookbook promotes re-use

- OpenSE Cookbook contributes to JPL institutional and project specific Cookbooks
- Project-independent modeling patterns as guidelines
- Project-specific modeling patterns for common modeling tasks

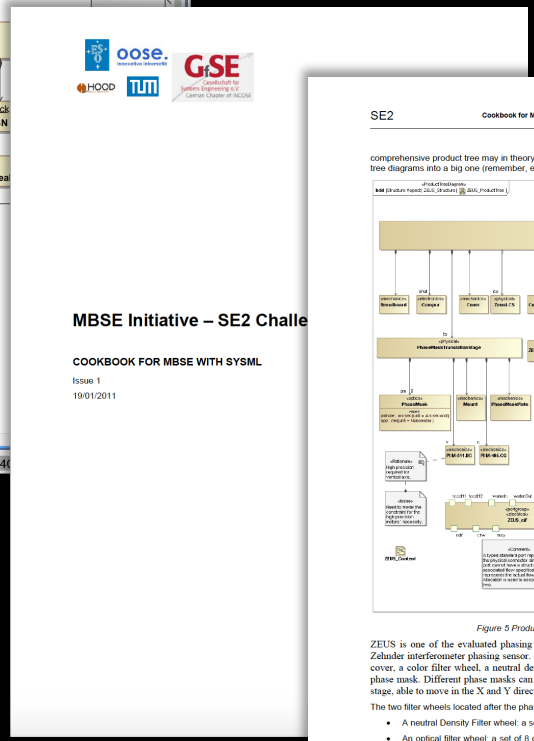


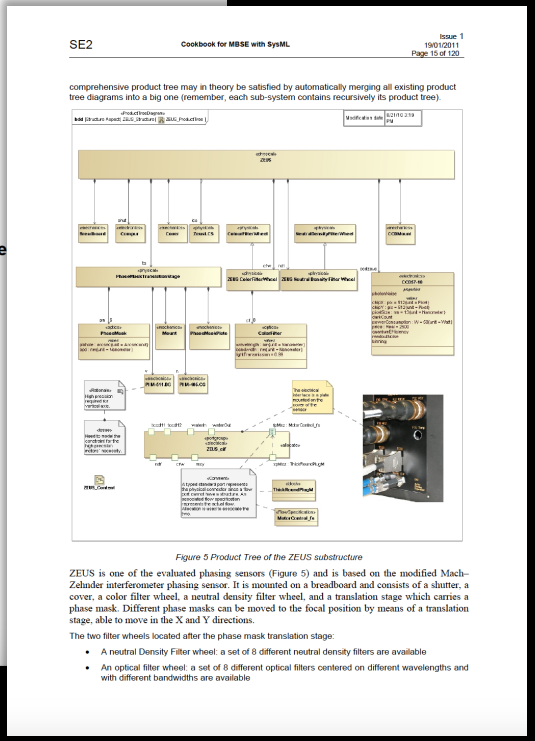
# OpenSE Cookbook and Template Model




"Cookbook" for modeling methodology & patterns

Template models to be used by projects as a starting point, with recommended organization, model libraries, etc.

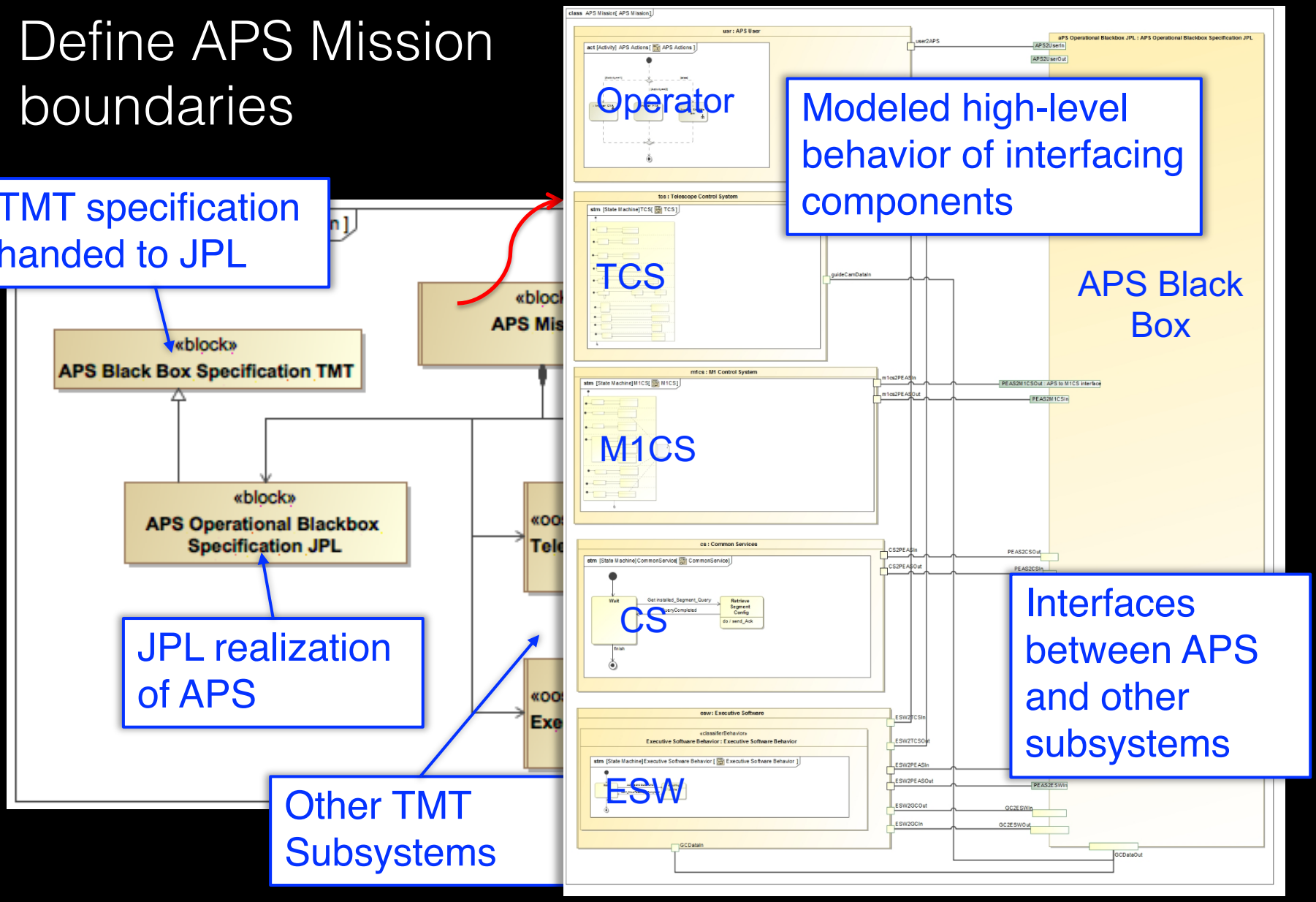


# OpenSE Cookbook is used as reference

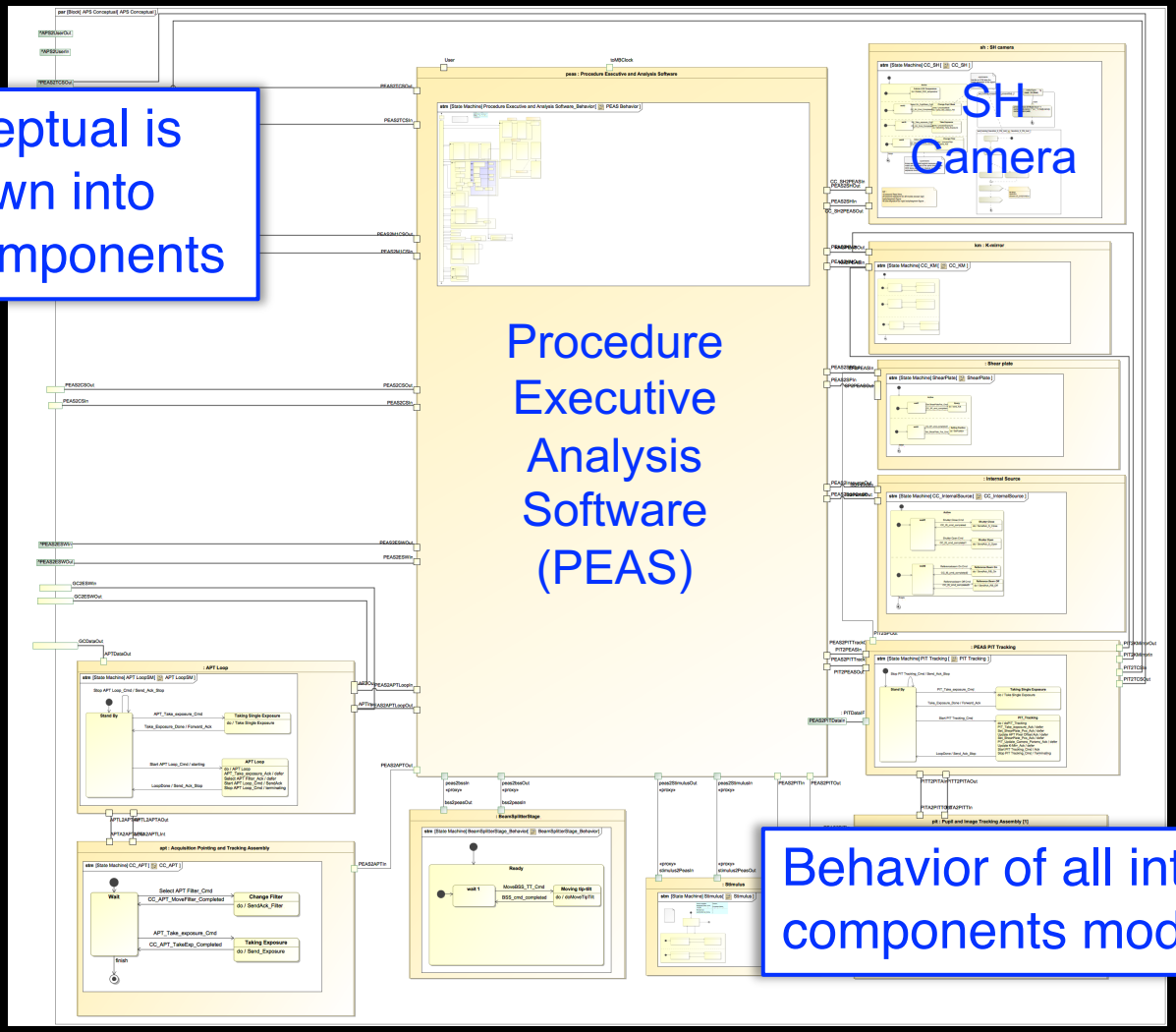
- OpenSE cookbook and TMT model used as reference model for the OMG SysML 2 standard
  - Demonstrate how SysML 2 will improve, simplify, change model wrt SysML 1.x
- Training material and knowledge transfer
- Promote standards and conventions
- Used by vendors as reference to test and evolve products

# Define APS Mission boundaries



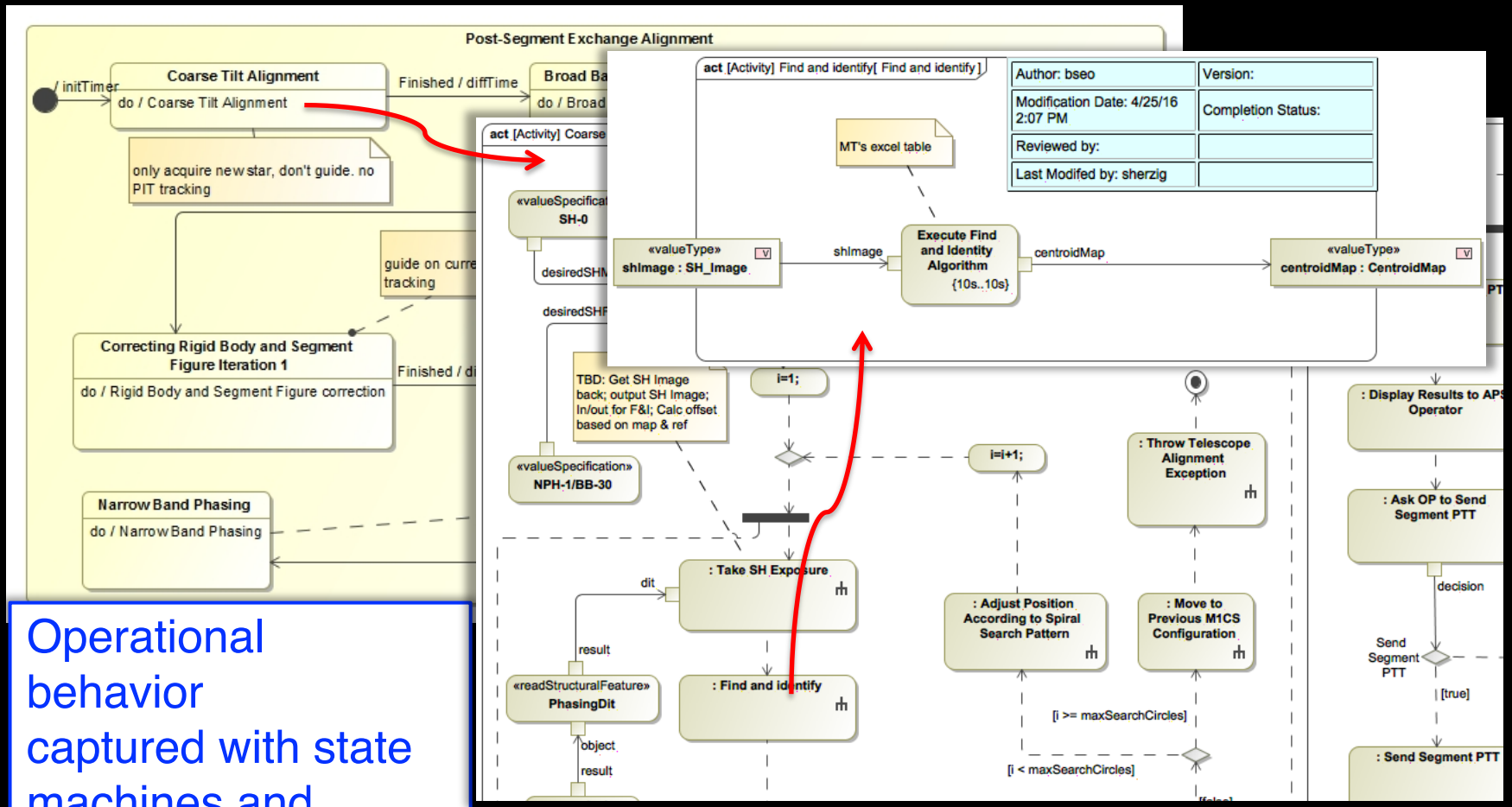
# Elaborate Conceptual Architecture

APS conceptual is broken down into several components



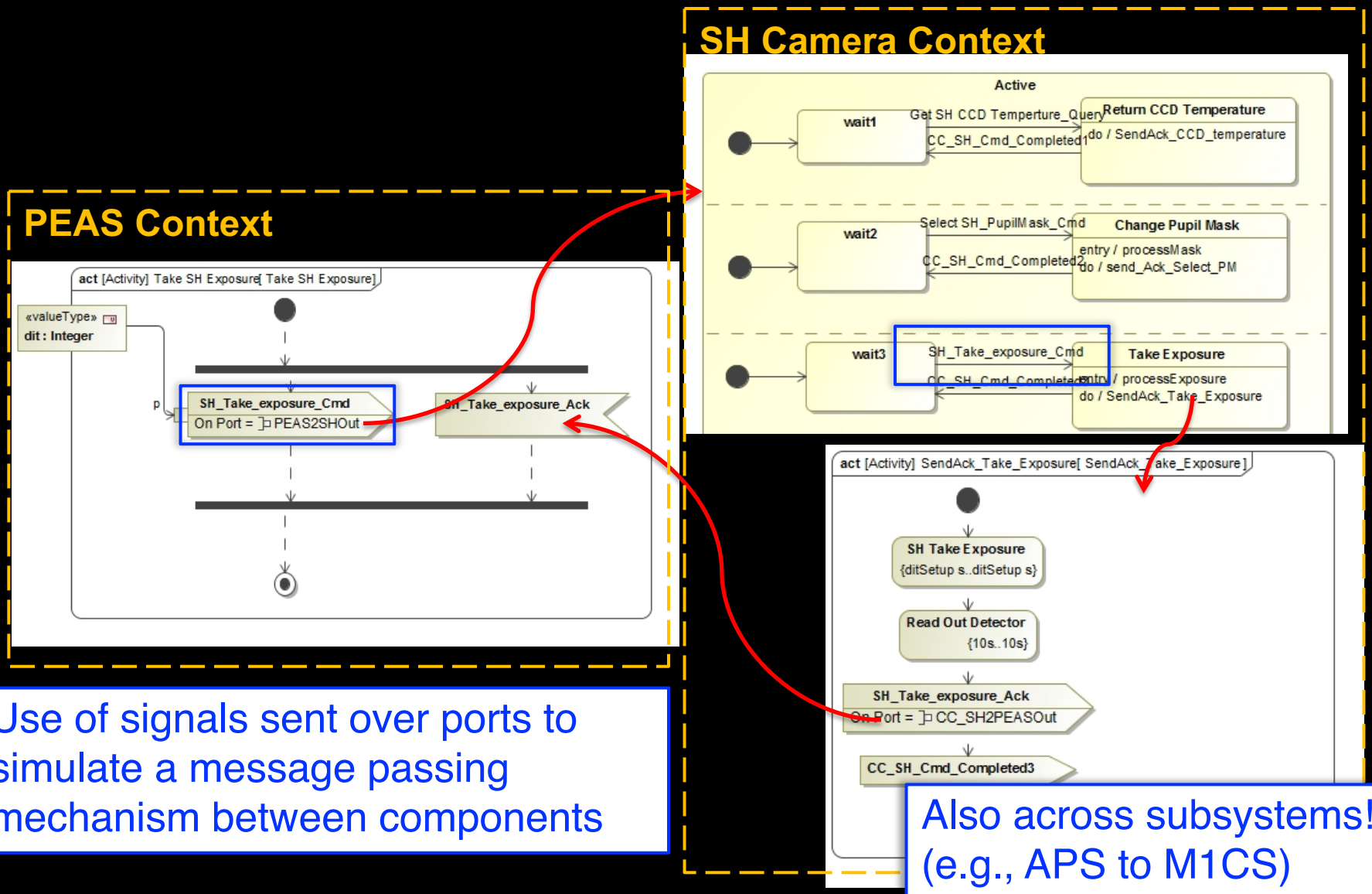

Behavior of all interacting components modeled

# Capture Component Behavior and Characteristics




Operational behavior captured with state machines and activity models

# Specify Interactions Between Components

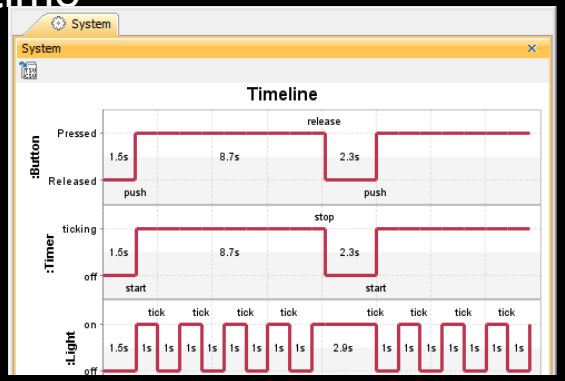


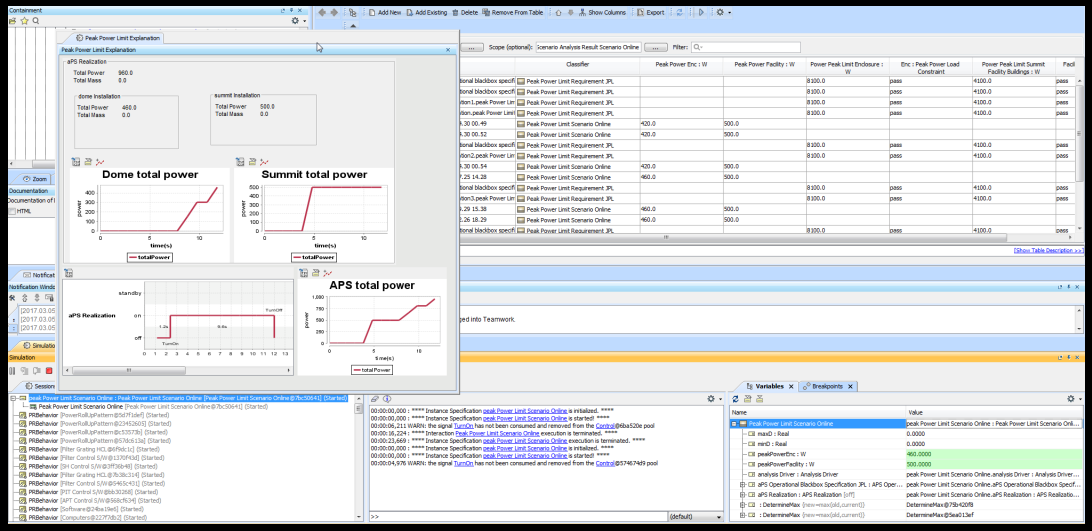

Use of signals sent over ports to simulate a message passing mechanism between components

Also across subsystems! (e.g., APS to M1CS)

# Run Analyses

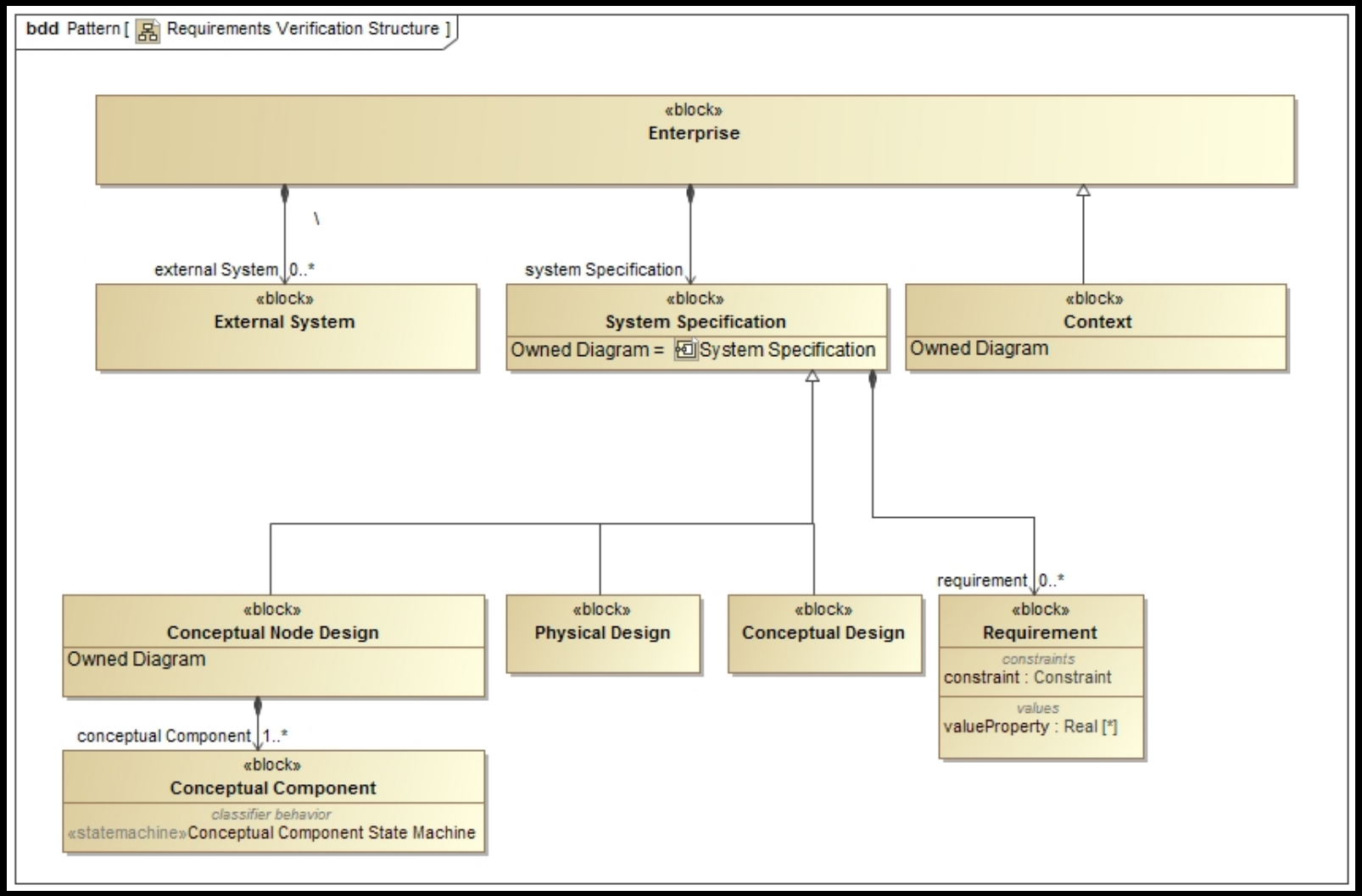
- Run a configured analysis with a simulation engine on the initial conditions to get the final conditions
- Produce the analyses declaratively, repeatably (in any system), without a single line of project-specific code -> reducing time and resources
- Produce the following views on final conditions
  - **Table** showing final analysis values (e.g. peak power) and the constraint's pass/fail status for each scenario
  - **Timelines**: state changes for components over time
  - **Value profiles**: total rolled up values over time



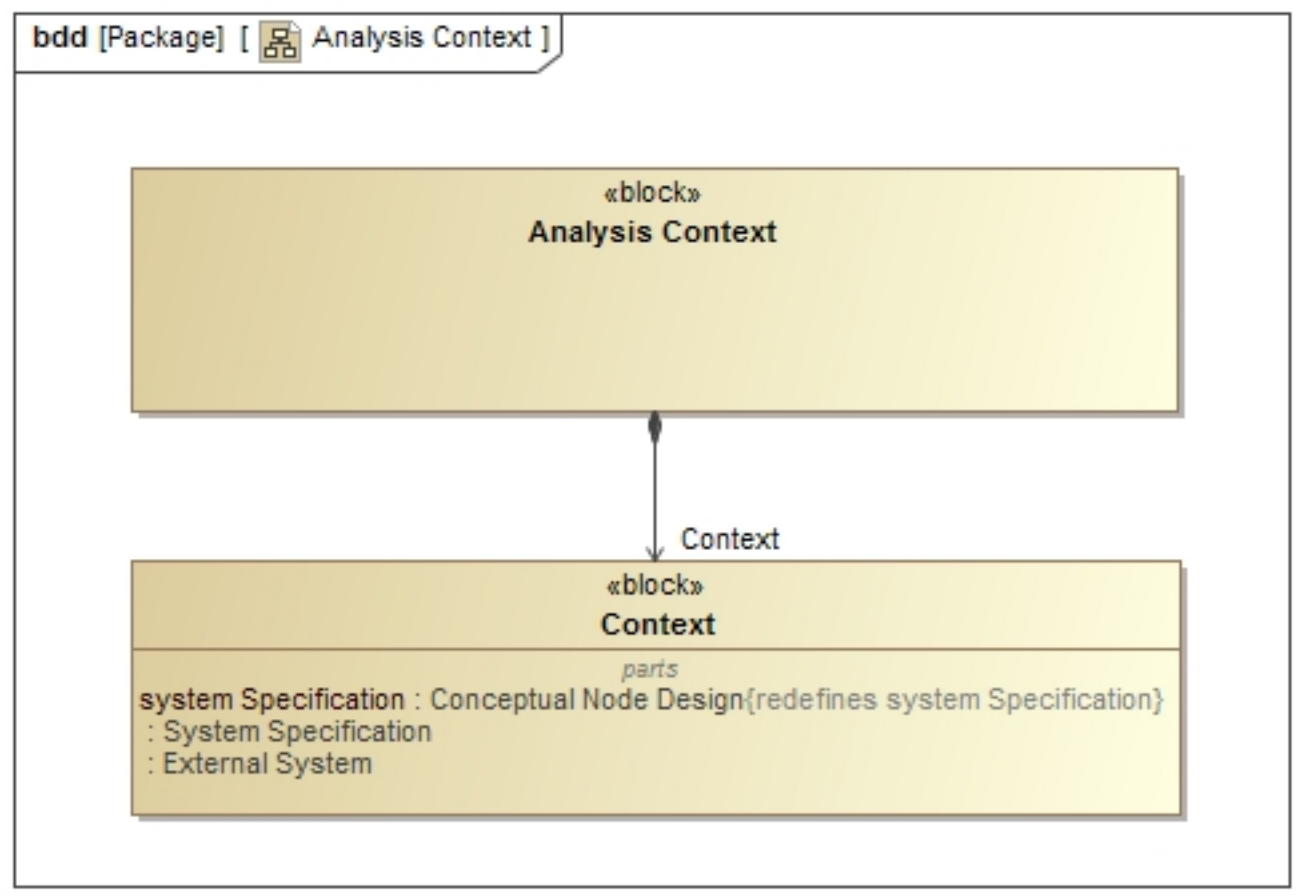




| # | Name | Classifier | T Final : Real | Ph |
|---|---|---|---|---|
| 1 | calibrations Duration S | Calibrations Duration S | | |
| 2 | calibrations Duration S | APS Conceptual | | |
| 3 | calibrations Duration S | Procedure Executive ar | 8466.0 | 11 |

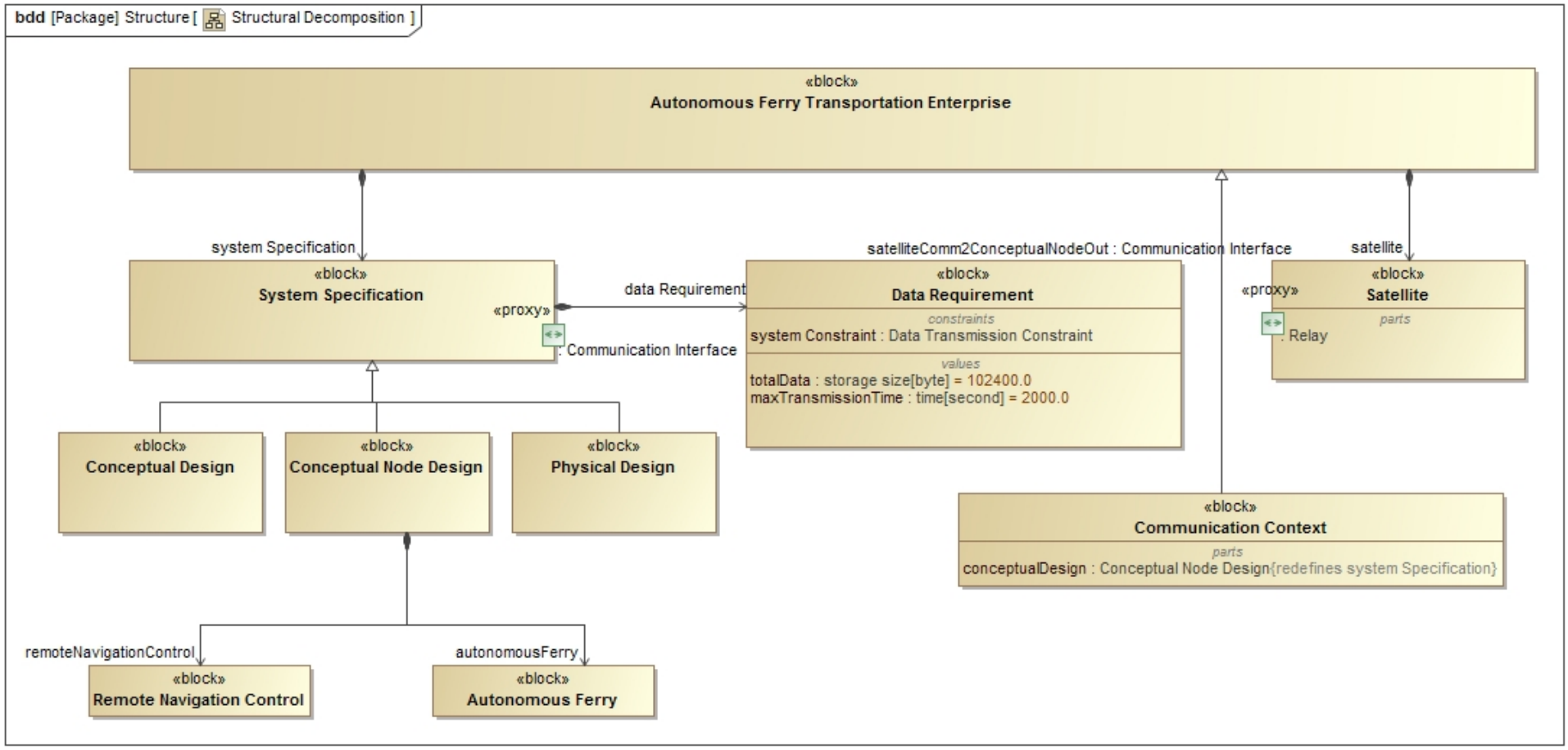
# System Context



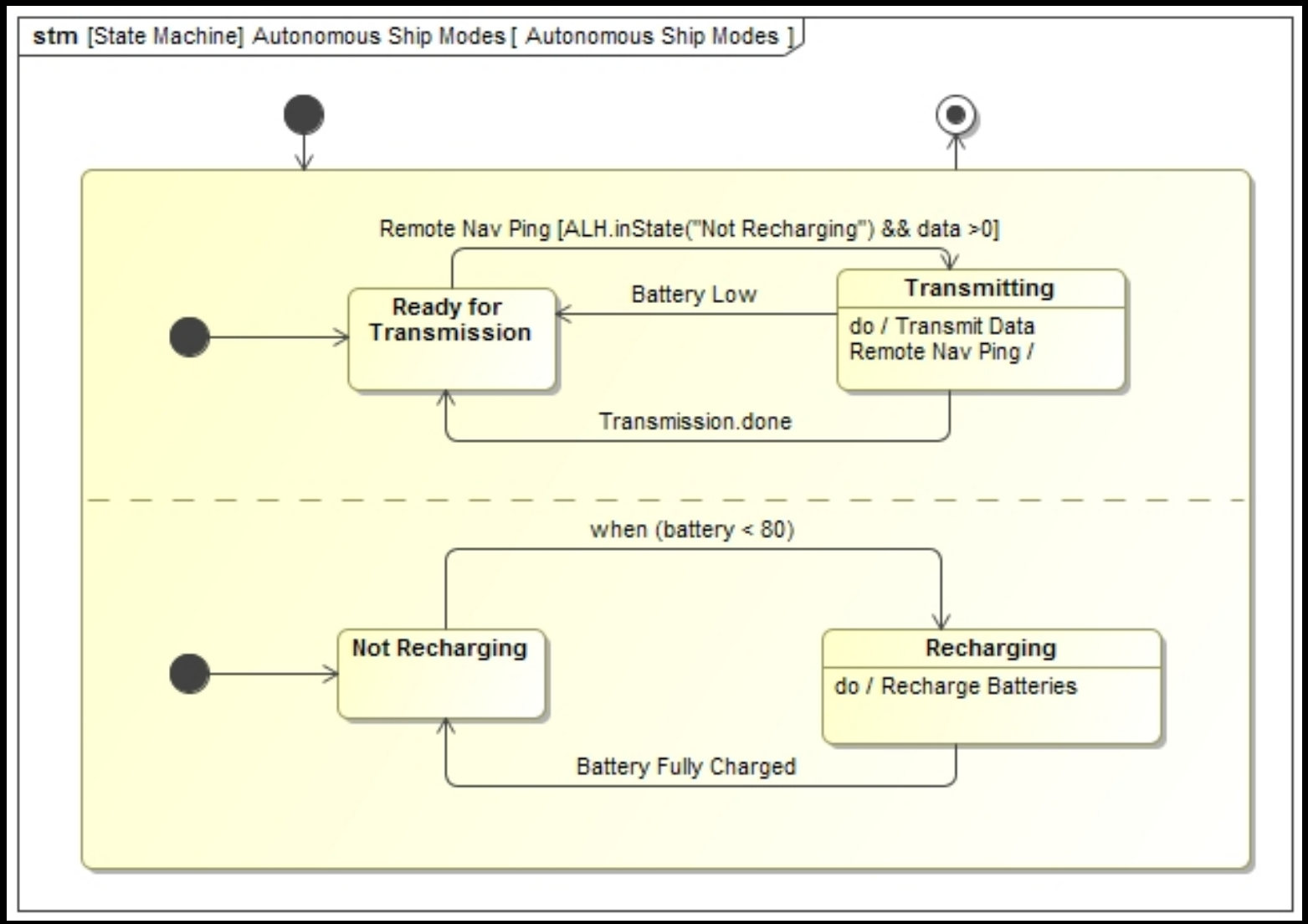
# Analysis Context



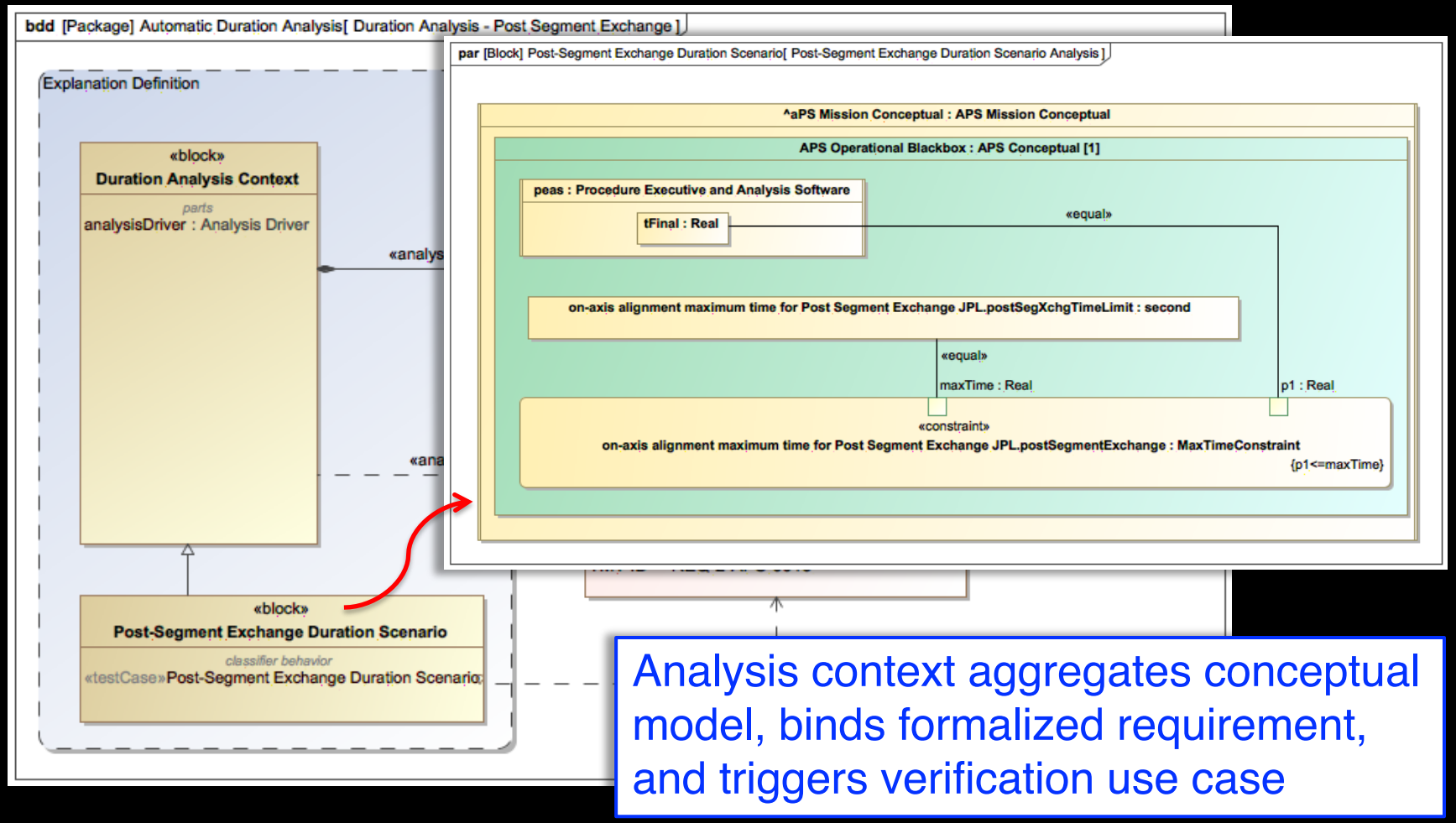
# Context Educational Example



# Behavior Ship

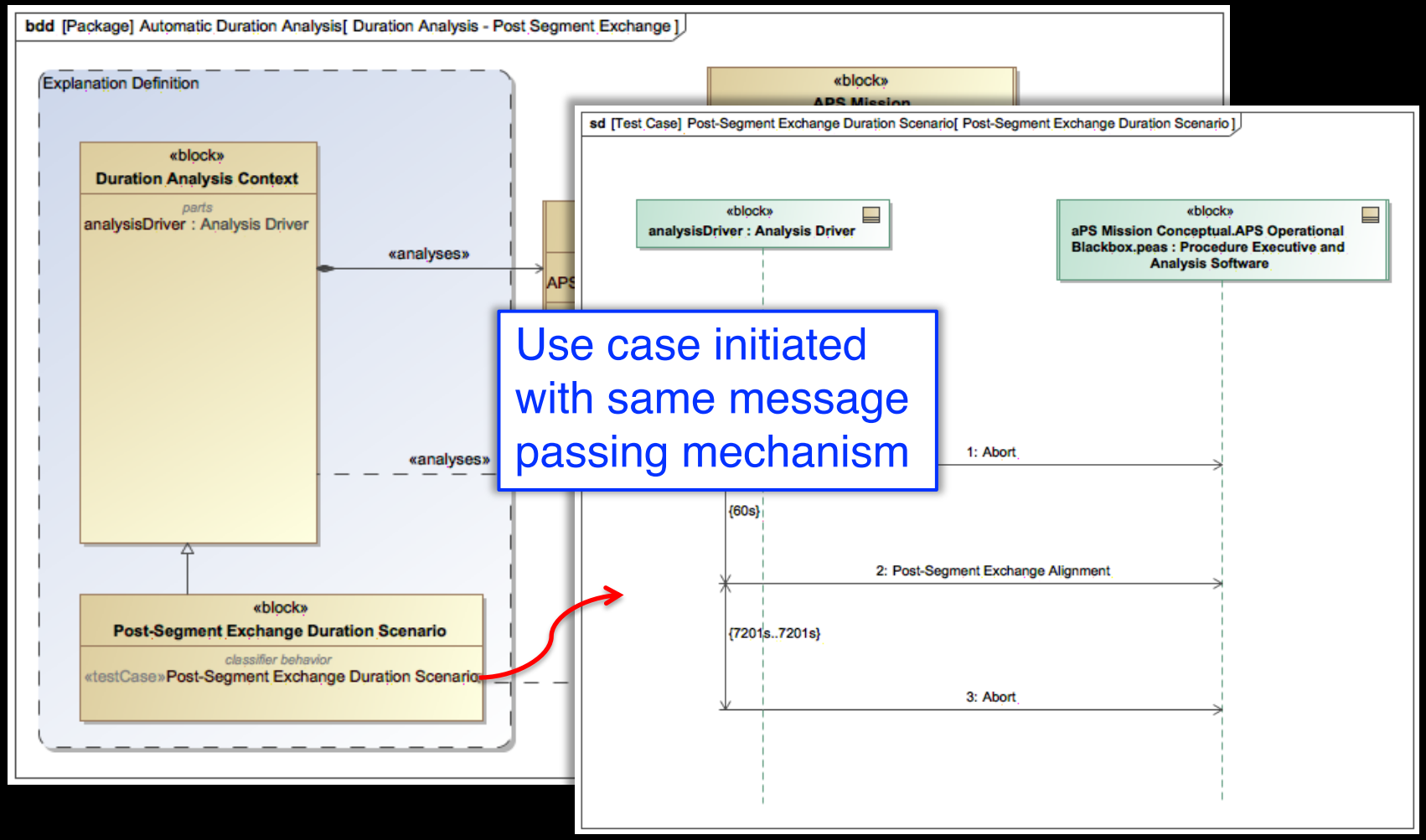


# Verifying Timing Requirements by Simulation

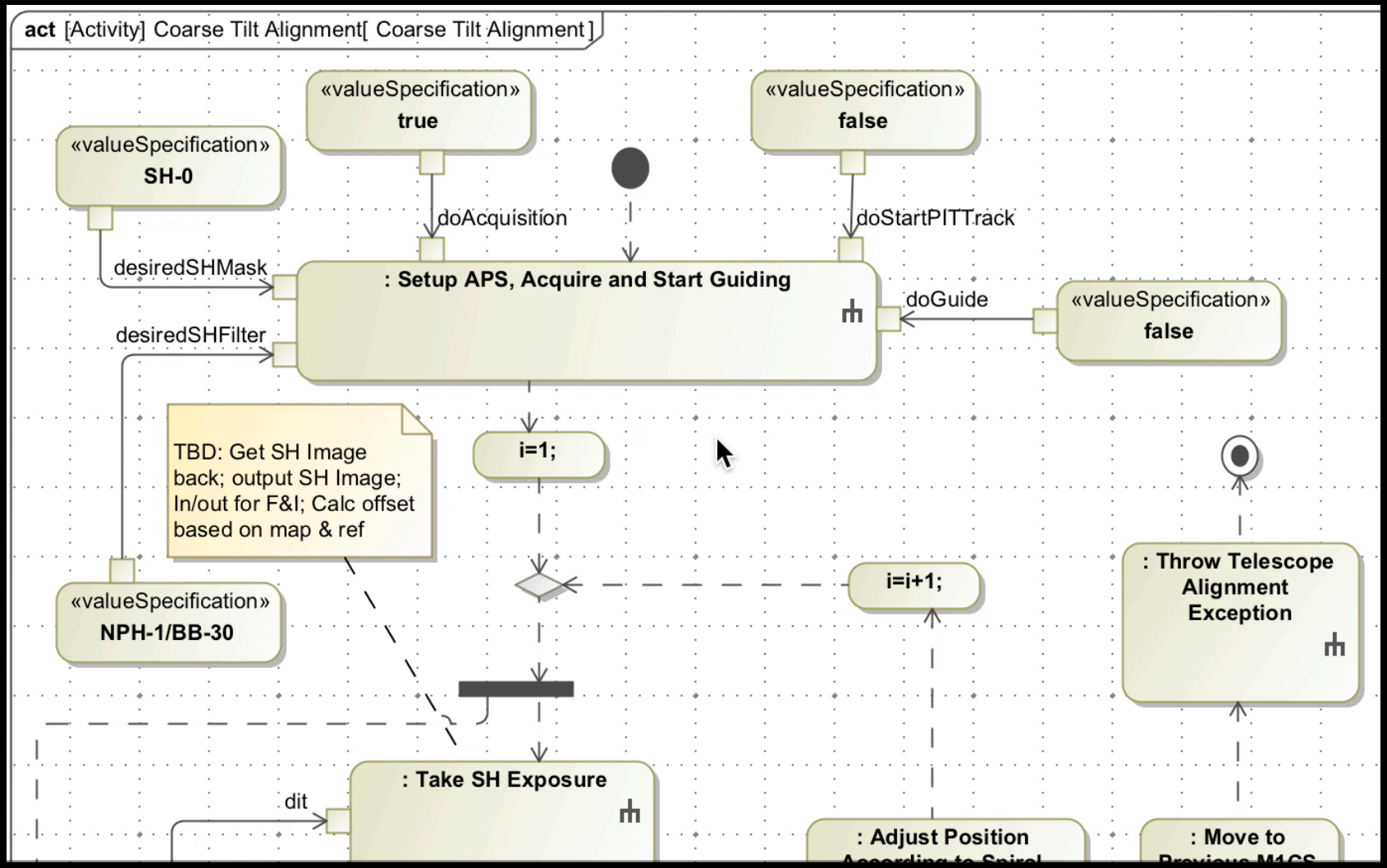



Analysis context aggregates conceptual model, binds formalized requirement, and triggers verification use case

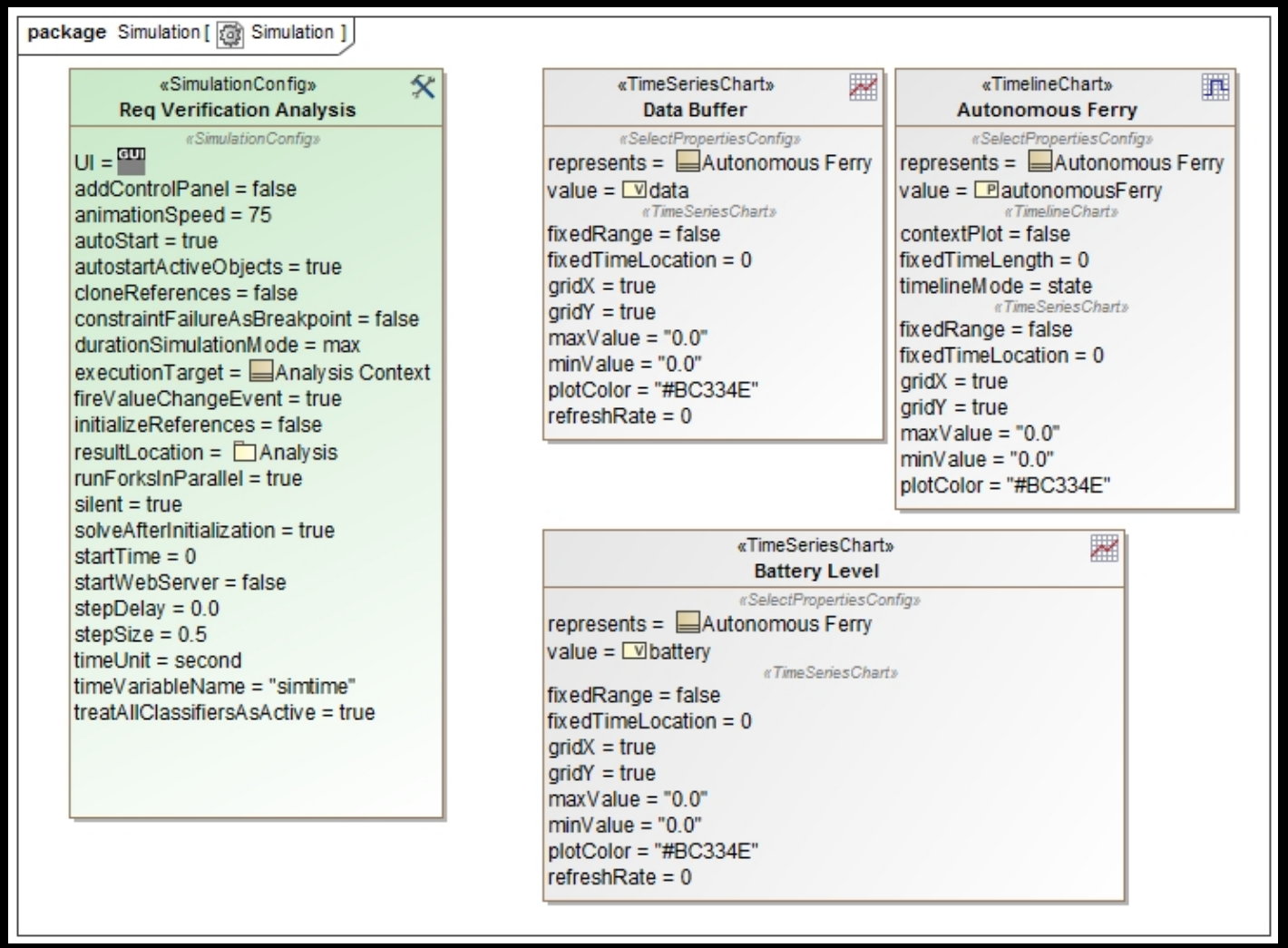
# Verifying Timing Requirements by Simulation



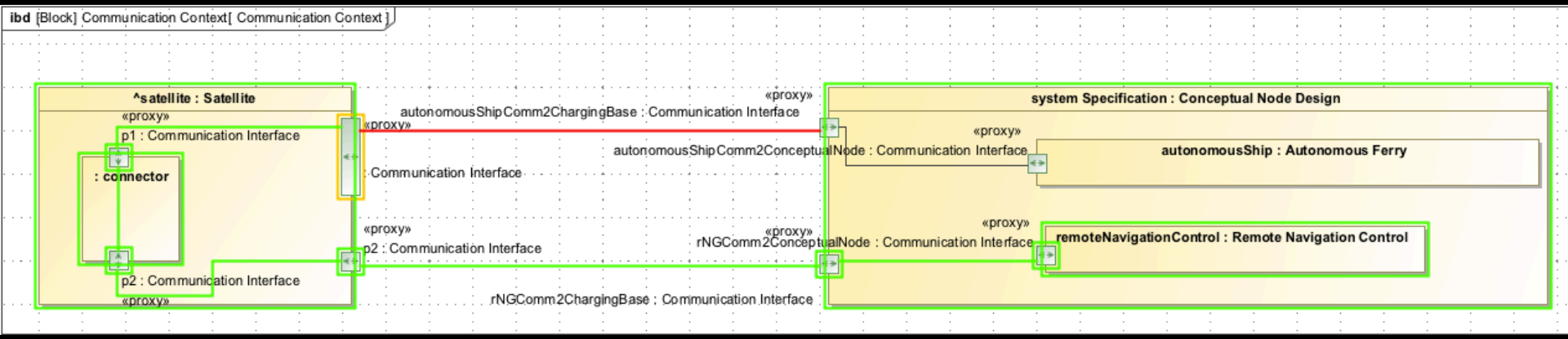
# Verifying Timing Requirements by Simulation



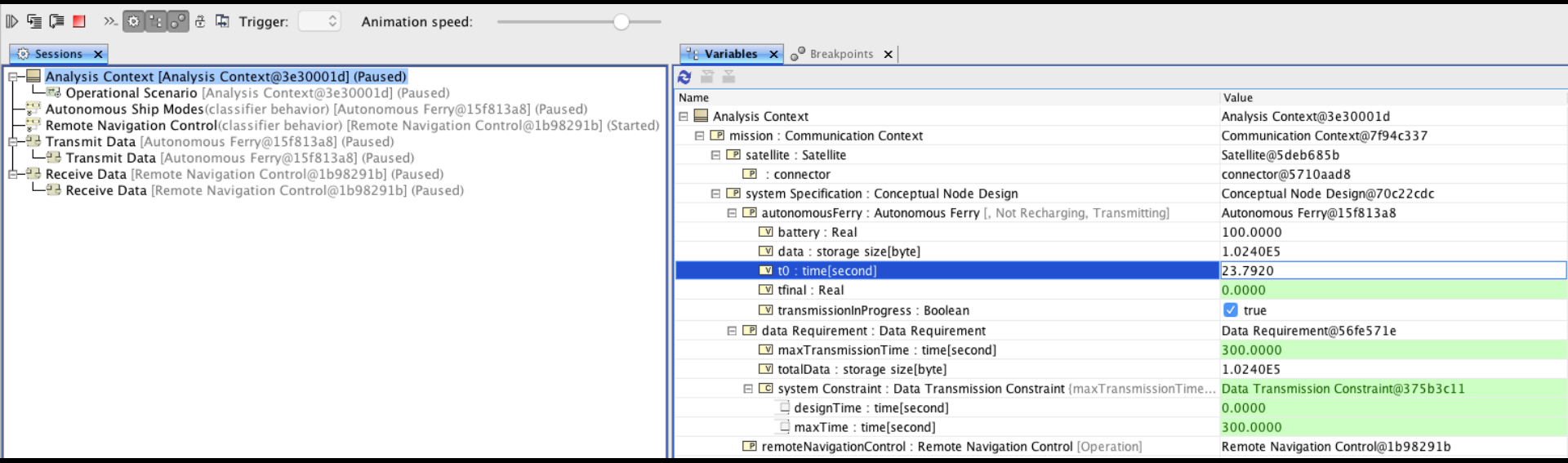
# Simulation Configuration with Cameo



# Executing a scenario



# Simulation Run



# Analysis by Simulation